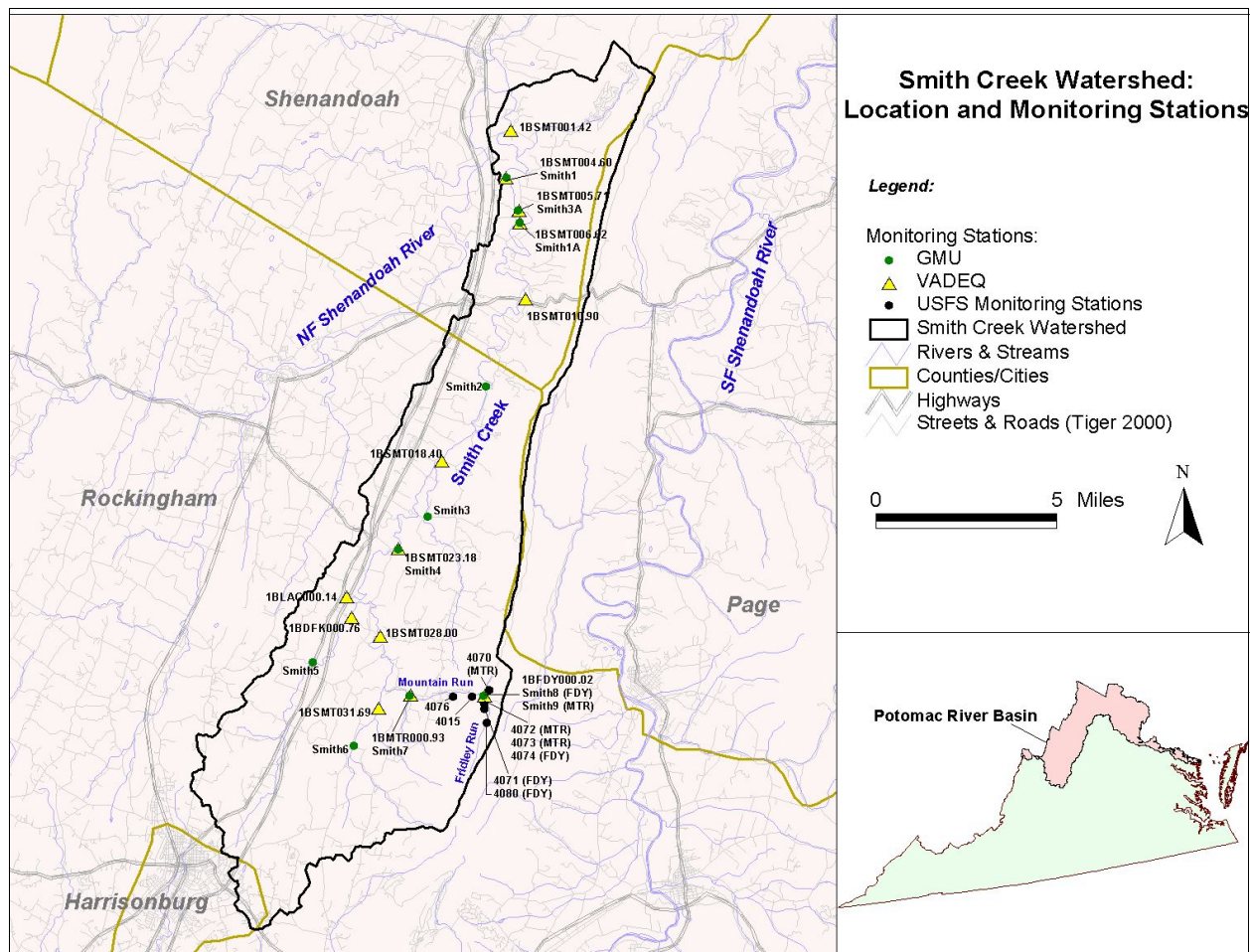


Total Maximum Daily Load (TMDL) Development for Smith Creek

Aquatic Life Use (Benthic) and E. coli (Bacteria) Impairments



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Executive Summary

Impairment Listing

The Smith Creek watershed (Virginia Waterbody Identification Code, VAV-B47R) is located in the Potomac River Basin in Shenandoah and Rockingham counties, with a small portion of the headwaters located in the City of Harrisonburg, Virginia (USGS Hydrologic Unit Code, 02070006) (Figure 1.1). The Smith Creek watershed is approximately 67,900 acres in size and land use is predominantly forest and agricultural.

Smith Creek was listed as impaired on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report due to violations of the State's Water Quality Standards for fecal coliform bacteria and violations of the General Standard (Benthics) (VADEQ 1998 & 2002a). Mountain Run and Fridley Run are tributaries to Smith Creek and are also listed as impaired due to violations of the General Standard (VADEQ 2002a). The Smith Creek bacteria impaired segment (31.18 miles) begins at the headwaters and continues downstream to the confluence with the North Fork Shenandoah River. The Smith Creek benthic impaired segment (22.39 miles) begins at the confluence with Lacey Springs Creek and ends at the North Fork Shenandoah River confluence. The lower portion of Smith Creek (15.71 miles) was also listed as "threatened" on the 2002 303(d) list due to high total phosphorus values. The Mountain Run impaired segment (5.41 miles) begins at the headwaters and ends at the Smith Creek confluence. The Fridley Run impaired segment (2.4 miles) begins at the headwaters and ends at the confluence with Mountain Run. * Note that an organic solids TMDL was recently developed for Lacey Spring Branch (VADEQ 2002).

Bacteria Impairment

Background

Elevated levels of fecal coliform bacteria and *E. coli* bacteria were recorded at several water quality monitoring stations on Smith Creek. In order to improve water quality conditions that have resulted in bacteria impairments, a Total Maximum Daily Load (TMDL) was developed for the impaired stream, taking into account all sources of bacteria in the watershed, plus an implicit margin of safety (MOS). Upon implementation, the bacteria TMDL will ensure that water quality conditions relating to bacteria impairment will meet the recently adopted *E. coli* criteria in Virginia's Water Quality Standards (9 VAC 25-260-170).

Sources of Bacteria

Point and nonpoint sources of bacteria in the Smith Creek watershed were considered in TMDL development. Agricultural runoff and wildlife are listed as the primary sources of bacteria, according to the 2002 303(d) Fact Sheet for Smith Creek. Nonpoint sources of bacteria include failing septic

systems and straight pipes, livestock (including manure application loads), wildlife, and domestic pets. Point sources, such as municipal sewage treatment plants, can contribute bacteria loads to surface waters through effluent discharges. There are currently 38 point source permits in the Smith Creek watershed, including a Municipal Separate Storm Sewer System (MS4) permit that was issued to the City of Harrisonburg to help control impacts caused by stormwater runoff from urban areas (Table 1). The bacteria load contributed by the MS4 permit during runoff events was calculated based on the modeling results for urban lands located within the City of Harrisonburg and the Smith Creek watershed. The bacteria load contributed by all other facilities was calculated based on the permitted flow and the applicable *E. coli* limit (126 cfu/100ml, geometric mean concentration).

* Note that the following permits do not discharge bacteria and were not included in the bacteria TMDL for Smith Creek: VA0091235, VAG110131, VAR100591, VAR102386, and VAR051331.

Table 1. VPDES point sources and existing loads

VPDES Permit No.	Facility	Flow (MGD)	Permit Limit (<i>E. coli</i> cfu/100ml)	Existing Annual Load (<i>E. coli</i> cfu/yr)
VA0027626	Valley View Mobile Home Court	0.0200	126	3.48E+10
VA0054453	New Market Poultry Products	0.3000	126	5.22E+11
VA0071846	Endless Caverns Inc	0.0046	126	8.01E+09
VA0080535	Two Hills Inc STP	0.0054	126	9.40E+09
VA0077399	Lacey Spring Elementary School STP	0.0075	126	1.31E+10
VA0090794	Holtzman Express-Mauzy	0.0060	126	1.04E+10
VA0088994	Harrisonburg-New Market KOA	0.0100	126	1.74E+10
VA0083305	Camp Overlook	0.0300	126	5.22E+10
VAG408049	Private Residence	0.0010	126	1.74E+09
VAG401001	Private Residence	0.0010	126	1.74E+09
VAG401128	Private Residence	0.0010	126	1.74E+09
VAG401201	Private Residence	0.0010	126	1.74E+09
VAG401179	Private Residence	0.0010	126	1.74E+09
VAG401363	Private Residence	0.0010	126	1.74E+09
VAG401492	Private Residence	0.0010	126	1.74E+09
VAG401537	Private Residence	0.0010	126	1.74E+09
VAG401551	Private Residence	0.0010	126	1.74E+09
VAG401405	Private Residence	0.0010	126	1.74E+09
VAG401890	Private Residence	0.0010	126	1.74E+09
VAG401956	Private Residence	0.0010	126	1.74E+09
VAG401966	Private Residence	0.0010	126	1.74E+09
VAG401961	Private Residence	0.0010	126	1.74E+09
VAG401805	Private Residence	0.0010	126	1.74E+09
VAG401920	Private Residence	0.0010	126	1.74E+09
VAG401432	Private Residence	0.0010	126	1.74E+09
VAG401988	Private Residence	0.0010	126	1.74E+09
VAG401998	Private Residence	0.0010	126	1.74E+09
VAG408026	Private Residence	0.0010	126	1.74E+09
VAG408028	Private Residence	0.0010	126	1.74E+09
VAG408029	Private Residence	0.0010	126	1.74E+09
VAG408030	Private Residence	0.0010	126	1.74E+09
VAG408035	Private Residence	0.0010	126	1.74E+09
VA0091235	Shenandoah Fisheries, Ltd	N/A	N/A	0
VAG110131	Superior Concrete Central Plant	N/A	N/A	0
VAR100591	Rockingham Redi-Mix Inc	N/A	N/A	0
VAR102386	Holtzman Express-Mauzy	N/A	N/A	0
VAR051331	Harper's Lawn Ornaments	N/A	N/A	0
VAR040075	City of Harrisonburg - MS4 Permit	N/A	126	2.88E+12
Total	All Permits	0.4075		3.59E+12

* MGD = million gallons per day

Modeling

An *E. coli* TMDL was developed using the Loading Simulation Program C++ (LSPC) model. LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model.

Weather conditions are the driving force for watershed hydrology processes. For the Smith Creek watershed simulation model, the required parameters included hourly precipitation and hourly potential evapotranspiration. There were no weather monitoring stations located within the Smith Creek watershed. Weather data collected at the Woodstock (449263) and Edinburg (442663) weather stations were used to setup the LSPC model. Available daily precipitation data were disaggregated to hourly measurements based on the hourly distribution of nearby weather stations.

Streamflow data were needed to calibrate the watershed hydrologic parameters in the LSPC model. Hourly streamflow data from the Smith Creek USGS gage (01632900) were used to calibrate hydrology. Representative flow data were available from 1980 through 2002. Two time periods were selected for hydrology calibration: 1990 through 1991 and 1996 through 1997. The land use coverage used in the model was developed during the mid 1990s; therefore, the selected calibration periods were consistent with this key model input. The model was then validated for long-term and seasonal representation of hydrologic trends using the current 13-year period (1990-2002). The calibration and validation periods covered a range of hydrologic conditions, including low and high flow conditions, as well as seasonal variation. The calibrated LSPC model adequately simulated the hydrology of the impaired watershed.

Following hydrology calibration, water quality was calibrated by comparing modeled versus observed in-stream fecal coliform bacteria concentrations. The water quality calibration consisted of executing the watershed model, comparing water quality time series output to available water quality observation data, and adjusting water quality parameters within a reasonable range.

Existing Conditions

The LSPC model was run for the representative hydrologic period January 1, 1990 through December 31, 2002. The modeling run represents the existing *E. coli* concentrations and loadings at the watershed outlet, using the DEQ fecal coliform bacteria/*E. coli* translator (VADEQ 2003). These data were compared to the 126 cfu/100mL geometric mean and 235 cfu/100mL instantaneous (single sample) water quality standards for *E. coli* to assess the magnitude of in-stream concentrations. Existing *E. coli* loadings by source category for Smith Creek are presented in Section 8. These values represent the contribution of bacteria from all sources in the watershed.

Margin of Safety

While developing allocation scenarios for the Smith Creek bacteria TMDL, an implicit margin of safety (MOS) was used. Conservative assumptions, the use of a detailed watershed model (LSPC), and other considerations were used in developing the bacteria TMDL, such that an explicit MOS was not necessary.

Allocation Scenarios

Load or wasteload allocations were assigned to each source category in the watershed. Various allocation scenarios were examined for reducing *E. coli* loads to levels that would result in the attainment of water quality standards (Table 2). Scenario 6 presents the source reductions required to achieve the *E. Coli* instantaneous and calendar month geometric mean criteria. Scenario 3 presents the reductions required to meet the Stage 1 implementation goal of <10% violation of the instantaneous criteria. Reductions in load contributions from in-stream sources had the greatest impact on *E. coli* concentrations. Significant reductions from land-based loadings were also required to meet the geometric mean standard.

Table 2. TMDL allocation scenarios and percent violations

Scenario Number	Direct (Instream) Sources			Indirect (NPS) Sources				Percent Violations	
	Straight Pipes	Livestock	Wildlife	Cropland	Pasture	Built up	Forest	Inst. Exceeds 235 cfu/100ml	Geom. Exceeds 126 cfu/100ml
1	0	0	0	0	0	0	0	20%	42%
2	50	50	0	50	50	50	0	11%	6%
3	100	60	0	50	50	60	0	10%	4%
4	75	75	0	75	75	75	0	5%	1%
5	80	80	0	85	85	85	0	2%	0%
6	100	95	0	92	92	95	0	0%	0%

The TMDL consists of a point source waste load allocation (WLA), a nonpoint source load allocation (LA), and an implicit margin of safety (MOS).

The WLA portion of this equation is the total loading assigned to point sources. The LA portion represents the loading assigned to nonpoint sources. The MOS is the portion of loading reserved to account for any uncertainty in the data and the computational methodology used for the analysis. TMDL allocations for Smith Creek (under Scenario 6) are presented in Tables 3 through 5.

Table 3. Existing and Allocation Loads for LAs under Allocation Scenario 6

Sources		Total Annual Loading for Existing Conditions (cfu/yr)	Total Annual Loading for Allocation Conditions (cfu/yr)	Percent Reduction
Direct	Straight Pipes	<1.00E+4	<1.00E+4	100%
	Livestock	1.68E+13	8.38E+11	95%
	Wildlife	2.64E+12	2.64E+12	0%
Indirect	Cropland*	3.45E+13	2.76E+12	92%
	Pasture**	5.93E+13	4.74E+12	92%
	Built up***	1.15E+13	5.77E+11	95%
	Forest****	8.65E+11	8.65E+11	0%
Total		1.26E+14	1.24E+13	90%

* Includes Barren

** Includes Hayland

*** Non MS4 Urban Pervious and Urban Impervious

**** Includes Wetland

Table 4. Existing and Allocation Loads for WLAs under Allocation Scenario 6

Sources	Total Annual Loading for Existing Conditions (E. coli cfu/yr)	Total Annual Loading for Allocation Conditions (E. coli cfu/yr)	Percent Reduction
Permits*	7.09E+11	7.09E+11	0%
MS4 - VAR040075	2.88E+12	1.44E+11	95%
Total	3.59E+12	8.53E+11	76%

* Total for all permits, excluding the Harrisonburg MS4 permit.

Table 5. *E. coli* TMDL for Smith Creek

WLA	LA	MOS	TMDL
8.53E+11	1.24E+13	Implicit	1.33E+13

Benthic Impairment

Background

Benthic stressor analyses indicate that the primary cause of the benthic community impairment in Smith Creek is excessive sedimentation. In order to improve water quality conditions that have resulted in benthic community impairments, a Total Maximum Daily Load (TMDL) was developed for Smith Creek, taking into account sources of sediment in the watershed, plus an explicit margin of safety (MOS). Upon implementation, the sediment TMDL will ensure that water quality conditions relating to benthic impairment will meet the allowable loadings estimated by use of a reference watershed (a non-impaired watershed with characteristics similar to those of the impaired watershed).

Sources of Sediment

Sediment sources can be divided into point and nonpoint sources. Sediment loads are primarily contributed by nonpoint sources in the Smith Creek watershed. The major sources of sediment are agricultural land and urban land. Agricultural lands, such as cropland and pasture/hay areas, can contribute excessive sediment loads through erosion and build-up/washoff processes. Agricultural lands are particularly susceptible to erosion due to less vegetative coverage.

There are currently 38 point source permits in the Smith Creek watershed, including a Municipal Separate Storm Sewer System (MS4) permit that was issued to the City of Harrisonburg to help control impacts caused by stormwater runoff from urban areas (see Table 6). All of these facilities potentially discharge sediment to streams in the Smith Creek watershed.

Table 6. VPDES point source facilities in the Smith Creek watershed

VPDES Permit No.	Facility Name	Receiving Stream
VA0027626	Valley View Mobile Home Court	Dry Fork X Trib
VA0054453	New Market Poultry Products	Smith Creek
VA0071846	Endless Caverns Inc	Smith Creek X Trib
VA0080535	Two Hills Inc STP	Smith Creek
VA0077399	Lacey Spring Elementary School STP	Lacey Spring, U.T.
VA0090794	Holtzman Express-Mauzy	Smith Creek
VA0091235	Shenandoah Fisheries, Ltd	Lacey Spring
VA0088994	Harrisonburg-New Market KOA	War Branch
VA0083305	Camp Overlook	Mountain Run
VAG408049	Private Residence	Smith Creek, UT
VAG401001	Private Residence	Smith Creek
VAG401128	Private Residence	Smith Creek, U.T.
VAG401201	Private Residence	Smith Creek
VAG401179	Private Residence	Smith Creek, U.T.
VAG401363	Private Residence	Smith Creek, U.T.
VAG401492	Private Residence	Smith Creek, U.T.
VAG401537	Private Residence	Smith Creek, U.T.
VAG401551	Private Residence	Smith Creek, U.T.
VAG401405	Private Residence	Smith Creek, U.T.
VAG401890	Private Residence	War Branch
VAG401956	Private Residence	Smith Creek, U.T.
VAG401966	Private Residence	Smith Creek UT
VAG401961	Private Residence	Smith Creek UT
VAG401805	Private Residence	Smith Creek, U.T.
VAG401920	Private Residence	Smith Creek, UT
VAG401432	Private Residence	Smith Creek
VAG401988	Private Residence	Smith Creek, U.T.
VAG401998	Private Residence	Smith Creek, U.T.
VAG408026	Private Residence	Dry Fork, U.T.
VAG408028	Private Residence	Smith Creek, U.T.
VAG408029	Private Residence	Smith Creek, U.T.
VAG408030	Private Residence	Smith Creek, U.T.
VAG408035	Private Residence	Smith Creek, U.T.
VAG110131	Superior Concrete Central Plant	Quarry in Smith Creek watershed
VAR100591	Rockingham Redi-Mix Inc	Dry Fork, UT
VAR102386	Holtzman Express-Mauzy	Smith Creek, UT
VAR051331	Harper's Lawn Ornaments	Dry Fork, UT
VAR040075	City of Harrisonburg MS4	N/A

Modeling

Sediment TMDLs were developed using BasinSim 1.0 and the GWLF model (Dai et al. 2000). GWLF is a continuous-simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment, based on daily water balance totals that are summed to give monthly values.

Virginia does not currently have numeric criteria for sediment; therefore, a reference watershed approach was used to determine the sediment load that corresponds with acceptable water quality and habitat conditions necessary to support aquatic life. This approach is based on selecting a non-impaired watershed that shares similar land use, ecoregion, and geomorphological characteristics with the impaired watershed. Stream conditions in the reference watershed are assumed to be representative of the conditions needed for the impaired stream to attain its designated uses. Sediment reductions required for the Smith Creek watershed were based on the reference sediment load that was calculated through modeling of the Hays Creek reference watershed.

Daily streamflow data were needed to calibrate watershed hydrologic parameters in the GWLF model. The USGS streamflow gage (01632900), located on Smith Creek near New Market, VA, was used to calibrate hydrology for the impaired watershed (Smith Creek). USGS gage station 02022500, located on Kerrs Creek near Lexington, VA, was used to calibrate hydrology for the reference watershed (Hays Creek). The calibration periods are April 1, 1991 - September 30, 2002 for the impaired watershed and April 1, 1991 through March 31, 1997 for the reference watershed. The calibration periods covered a range of hydrologic conditions, including low and high flow conditions, as well as seasonal variation. The calibrated GWLF model adequately simulated the hydrology of the impaired and reference watersheds.

Existing Conditions

Impaired and reference watershed models were calibrated for hydrology using different modeling periods and weather input files. To establish baseline (reference watershed) loadings for sediment the GWLF model for Hays Creek was used. For TMDL calculation the calibrated impaired and reference watersheds were run for an 12-year period from 4/1/1990 to 3/31/2002. The total area for the reference watershed was reduced to be equal to its paired target watershed. This was necessary because watershed size influences sediment delivery to the stream and other model variables.

The 11-year means for sediment were determined for each land use/source category in the reference and the impaired watersheds, respectively. These modeling periods were used, after calibration, to represent a broad range of recent weather and hydrologic conditions.

Margin of Safety

While developing allocation scenarios for the sediment TMDL, an explicit margin of safety (MOS) of 10% was used. 10% of the reference sediment load was calculated and added to the sum of the load allocation (LA) and wasteload allocation (WLA) to produce the TMDL. It is assumed that this MOS will account for any uncertainty in the data and the computational methodology used for the analysis, as well as provide an additional level of protection for designated uses.

Allocation Scenarios

Load or wasteload allocations were assigned to each source category in the Smith Creek watershed. Several allocation scenarios were developed for the watershed to examine the outcome of various load reduction combinations. The recommended scenario for Smith Creek (Table 7) is based on maintaining the existing percent load contribution from each source category. Two additional scenarios are presented for comparison purposes (Table 8). Load reductions from agricultural sources are minimized in the first alternative and reductions from urban lands are minimized in the second alternative. The recommended scenario balances the reductions from agricultural and urban sources by maintaining existing watershed loading characteristics. In each scenario, loadings from certain source categories were allocated according to their existing loads. For instance, sediment loads from forest lands represent the natural condition that would be expected to exist; therefore, the loading from forest lands was not reduced. Also, sediment loads from point sources were not reduced because these facilities are currently meeting their pollutant discharge limits and other permit requirements and because current permit requirements are expected to result in attainment of the WLAs as required by the TMDL. Note that the sediment WLA values presented in the following tables represent the sum of all point source WLAs. The estimated sediment loads contributed to the watershed by all permitted facilities are shown in Table 9.

Table 7. Recommended sediment allocations for Smith Creek

Source Category	Sediment Load Allocation (lbs/yr)	Sediment % Reduction
Forest	299,718	0.0%
Water	0	0.0%
Pasture/Hay	19,040,555	22.0%
Cropland	4,221,267	22.0%
Transitional	363,059	22.0%
Urban (pervious & impervious)	77,623	22.0%
Groundwater	0	0.0%
Point Sources	334,069	0.0%
MS4	19,798	22.0%
TMDL Load (minus MOS)	24,356,089	21.6%

Table 8. Alternative sediment allocations for Smith Creek

Source Category	Minimize Agricultural Reductions	Minimize Urban Reductions
Forest	0.0%	0.0%
Water	0.0%	0.0%
Pasture/Hay	20.5%	22.5%
Cropland	20.5%	22.0%
Transitional	97.0%	0.0%
Urban (pervious & impervious)	97.0%	0.0%
Groundwater	0.0%	0.0%
Point Sources	0.0%	0.0%
MS4 Permit	97.0%	0.0%

Table 9. Sediment wasteload allocation for the Smith Creek watershed

VPDES Permit No.	Facility Name	Discharge Type	Design Flow (MGD)	Permitted Concentration (mg/L) or Load (kg/day)	TSS load (lbs/yr)
VA0027626	Valley View Mobile Home Court	General	0.02	45	2,735.9
VA0054453	New Market Poultry Products	General	0.3	147	134,382.8
VA0071846	Endless Caverns Inc	General	0.0046	117	1,641.6
VA0080535	Two Hills Inc STP	General	0.0054	45	740.3
VA0077399	Lacey Spring Elementary School STP	General	0.0075	45	1,030.0
VA0090794	Holtzman Express-Mauzy	General	0.006	45	820.8
VA0091235	Shenandoah Fisheries, Ltd	General	N/A	0.46 kg/day average (final permit limit)	370.2
VA0088994	Harrisonburg-New Market KOA	General	0.01	45	1,368.0
VA0083305	Camp Overlook	General	0.03	45	4,112.0
VAG408049	Private Residence	Stormwater	N/A	30	91.4
VAG401001	Private Residence	Stormwater	N/A	30	91.4
VAG401128	Private Residence	Stormwater	N/A	30	91.4
VAG401201	Private Residence	Stormwater	N/A	30	91.4
VAG401179	Private Residence	Stormwater	N/A	30	91.4
VAG401363	Private Residence	Stormwater	N/A	30	91.4
VAG401492	Private Residence	Stormwater	N/A	30	91.4
VAG401537	Private Residence	Stormwater	N/A	30	91.4
VAG401551	Private Residence	Stormwater	N/A	30	91.4
VAG401405	Private Residence	Stormwater	N/A	30	91.4
VAG401890	Private Residence	Stormwater	N/A	30	91.4
VAG401956	Private Residence	Stormwater	N/A	30	91.4
VAG401966	Private Residence	Stormwater	N/A	30	91.4
VAG401961	Private Residence	Stormwater	N/A	30	91.4
VAG401805	Private Residence	Stormwater	N/A	30	91.4
VAG401920	Private Residence	Stormwater	N/A	30	91.4
VAG401432	Private Residence	Stormwater	N/A	30	91.4
VAG401988	Private Residence	Stormwater	N/A	30	91.4
VAG401998	Private Residence	Stormwater	N/A	30	91.4
VAG408026	Private Residence	Stormwater	N/A	30	91.4
VAG408028	Private Residence	Stormwater	N/A	30	91.4
VAG408029	Private Residence	Stormwater	N/A	30	91.4
VAG408030	Private Residence	Stormwater	N/A	30	91.4
VAG408035	Private Residence	Stormwater	N/A	30	91.4
VAG110131	Superior Concrete Central Plant	Stormwater	N/A	30	91.4
VAR100591	Rockingham Redi-Mix Inc	Stormwater	N/A	100	98,000.1
VAR102386	Holtzman Express-Mauzy	Stormwater	N/A	100	69,253.4
VAR051331	Harper's Lawn Ornaments	Stormwater	N/A	100	17,329.7
VAR040075	City of Harrisonburg MS4	Stormwater	N/A	N/A	19,797.6
Total Load					353,867.0

The TMDL established for this stream consists of a point source wasteload allocation (WLA), a nonpoint source load allocation (LA), and a margin of safety (MOS). The sediment TMDL was based on the total load calculated for the Hays Creek watershed (area adjusted to the appropriate watershed size).

The TMDL equation is as follows:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

The WLA portion of this equation is the total loading assigned to point sources. The LA portion represents the loading assigned to nonpoint sources. The MOS is the portion of loading reserved to account for any uncertainty in the data and the computational methodology used for the analysis.

A TMDL was calculated by adding reference watershed loads for sediment together with point source loads to give the TMDL value (Table 10).

Table 10. Sediment TMDL for the Smith Creek watershed

TMDL (lbs/yr)	WLA (lbs/yr) (including MS4)	LA (lbs/yr)	MOS (lbs/yr)	Overall % Reduction
27,062,901	353,867	24,002,222	2,706,812	21.6%

SECTION 1

INTRODUCTION

1.1 Background

1.1.1 TMDL Definition and Regulatory Information

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources (USEPA 1991).

1.1.2 Impairment Listing

Smith Creek was listed as impaired on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report due to violations of the State's Water Quality Standards for fecal coliform bacteria and violations of the General Standard (Benthics) (VADEQ 1998 & 2002a). Mountain Run and Fridley Run are tributaries to Smith Creek and are also listed as impaired due to violations of the General Standard (VADEQ 2002a). The Smith Creek bacteria impaired segment (31.18 miles) begins at the headwaters and continues downstream to the confluence with the North Fork Shenandoah River. The Smith Creek benthic impaired segment (22.39 miles) begins at the confluence with Lacey Springs Branch and ends at the North Fork Shenandoah River confluence. The lower portion of Smith Creek (15.71 miles) was also listed as "threatened" on the 2002 303(d) list due to high total phosphorus values. The Mountain Run impaired segment (5.41 miles) begins at the headwaters and ends at the Smith Creek confluence. The Fridley Run impaired segment (2.4 miles) begins at the headwaters and ends at the confluence with Mountain Run. * Note that an organic solids TMDL was recently developed for Lacey Spring Branch (VADEQ 2002b).

1.1.3 Watershed Location

The Smith Creek watershed (Virginia Waterbody Identification Code, VAV-B47R) is located in the Potomac River Basin in Shenandoah and Rockingham counties, with a small portion of the

headwaters located in the City of Harrisonburg, Virginia (USGS Hydrologic Unit Code, 02070006) (Figure 1.1).

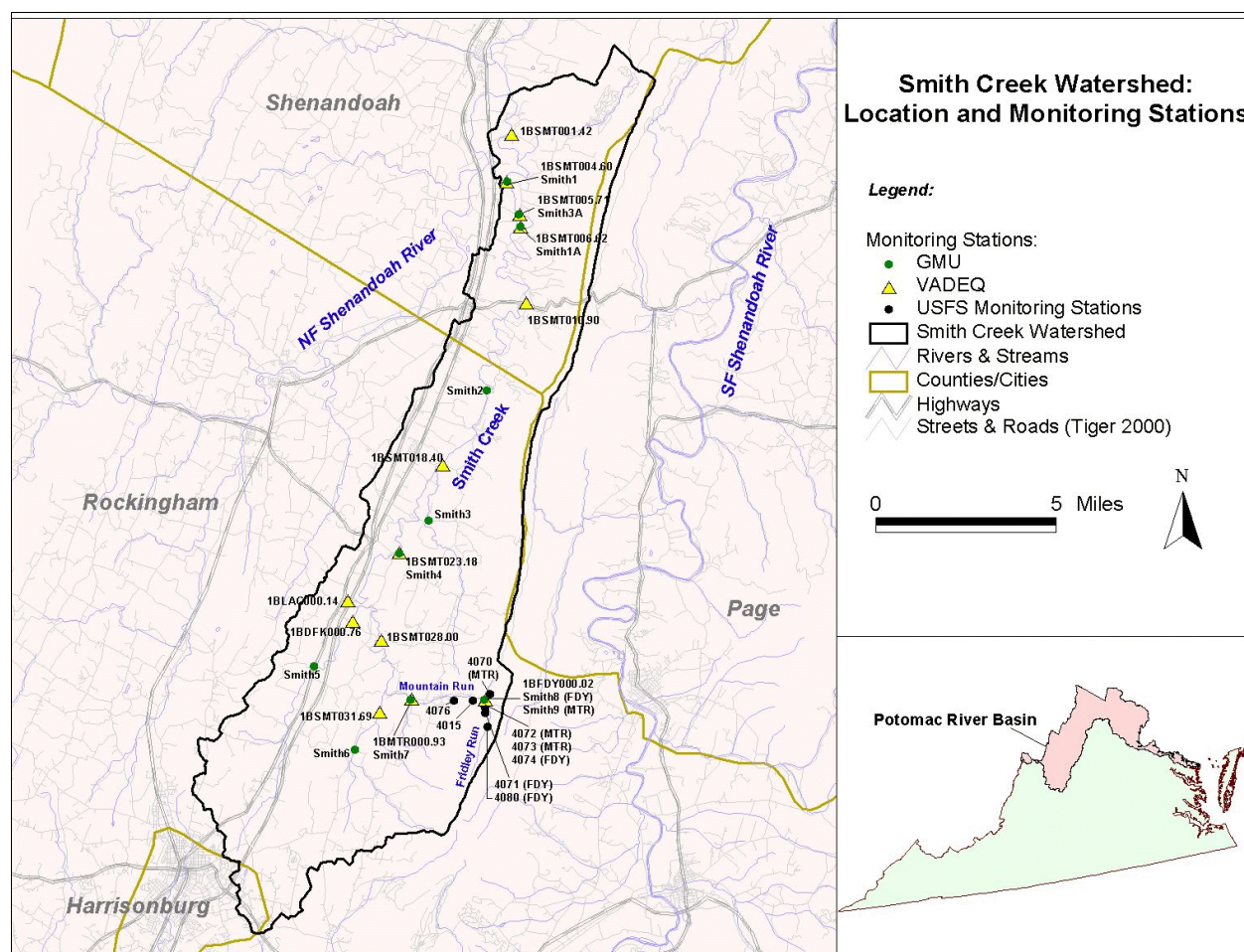


Figure 1.1 Location of the Smith Creek watershed

1.2 Designated Uses and Applicable Water Quality Standards

According to Virginia's Water Quality Standards (9 VAC 25-260-5), the term "Water quality standards" means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§ 62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC § 1251 et seq.).

1.2.1 Designation of Uses (9 VAC 25-260-10)

A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.

Smith Creek does not support the recreation (swimming) designated use due to violations of the Bacteria Criteria. Smith Creek, Mountain Run, and Fridley Run partially support the aquatic life designated use due to violations of the General Criteria (Benthic).

1.2.2 Water Quality Standards

Bacteria (9 VAC 25-260-170)

Beaver Creek was listed as impaired on Virginia's 1998 and 2002 303(d) list for non-compliance with the following fecal coliform bacteria criteria:

A. General Requirements: In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.

Virginia's Water Quality Standards were amended to include new criteria for fecal coliform bacteria, *E. coli*, and *enterococci*. Standards were adopted for *E. coli* and *enterococci* because of the higher correlation between *E. coli* and *enterococci* concentrations and gastrointestinal illness. These new criteria became effective on January 15, 2003. Fecal coliform bacteria and *E. coli* criteria apply to Beaver Creek, which is a freshwater stream. Bacteria concentrations are expressed as the number of colony forming units per 100ml of water (cfu/100ml):

A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:

1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.

2. *E. coli* and enterococci bacteria per 100 ml of water shall not exceed the following:

	Geometric Mean ¹	Single Sample Maximum ²
<i>Freshwater</i> ³		
<i>E. coli</i>	126	235
<i>Saltwater and Transition Zone</i> ³		
enterococci	35	104

¹ For two or more samples taken during any calendar month.

² No single sample maximum for enterococci and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

³ See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

General Criteria (9 VAC 25-260-20)

- A. *All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.*

Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled.

1.3 Water Quality Assessment and TMDL Endpoint Selection

1.3.1 Bacteria Assessment

Smith Creek was listed as impaired for fecal coliform bacteria on Virginia's 303(d) list based on monitoring conducted by VADEQ. Elevated levels of fecal coliform bacteria were recorded at two water quality monitoring stations on Smith Creek. VADEQ began monitoring for *E. coli* in 2000 in anticipation of the change in indicator species. Elevated levels of *E. coli* have also been recorded on Smith Creek. As a result, Smith Creek does not currently support the Recreation (swimming) designated use.

TMDL development requires the identification of a numeric endpoint that will allow for the attainment of designated uses and water quality criteria. The new fecal coliform bacteria criteria specified in 9 VAC 25-260-170 shall not apply after a minimum of 12 samples for *E. coli* have been collected or after June 30, 2008, whichever comes first. As a result, the applicable TMDL endpoint is compliance with the recently adopted *E. coli* criteria. Virginia's Water Quality Standards specify a maximum *E. coli* bacteria concentration of 235 cfu/100ml, at any time, and a geometric mean criteria of 126 cfu/100 ml for two or more samples over the calendar month period (9 VAC 25-260-170).

1.3.2 Biomonitoring and Assessment

Direct investigations of biological communities using rapid bioassessment protocols, or other biosurvey techniques, are best used for detecting aquatic life impairments and assessing their relative severity (Plafkin et al. 1989). Biological communities reflect overall ecological integrity; therefore, biosurvey results directly assess the status of a waterbody relative to the primary goal of the Clean Water Act. Biological communities integrate the effects of different pollutant stressors and thus provide a holistic measure of their aggregate impact. Communities also integrate the stresses over time and provide an ecological measure of fluctuating environmental conditions.

Many state water quality agencies use benthic macroinvertebrate community data to assess the biological condition of a waterbody. Virginia uses EPA's Rapid Bioassessment Protocol (RBP II) to determine the status of a stream's benthic macroinvertebrate community. This procedure relies on comparisons of the benthic macroinvertebrate community between a monitoring station and its designated reference site. Measurements of the benthic community, called metrics, are used to identify differences between monitored and reference stations. Metrics used in the RBP II protocol include taxa richness, percent contribution of dominant family, and other measurements that provide information on the abundance of pollution tolerant versus pollution intolerant organisms. Biomonitoring stations are typically sampled in the spring and fall of each year. The biological condition scoring criteria and the bioassessment matrix are discussed in the technical document, *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish* (Plafkin et al. 1989). The RBPII bioassessment scoring matrix is presented in Table 1.1.

Table 1.1 Bioassessment scoring matrix (Plafkin et al. 1989)

% Compare to Reference Score (a)	Biological Condition Category	Attributes
>83%	Non-Impaired	Optimum community structure (composition and dominance).
54 - 79%	Slightly Impaired	Lower species richness due to loss of some intolerant forms.
21 - 50%	Moderately Impaired	Fewer species due to loss of most intolerant forms.
<17%	Severely Impaired	Few species present. Dominant by one or two taxa. Only tolerant organisms present.
(a) Percentage values obtained that are intermediate to the above ranges require subjective judgement as to the correct placement.		

Virginia 305(b)/303(d) guidance states that support of the aquatic life beneficial use is determined by the assessment of conventional pollutants (dissolved oxygen, pH, and temperature); toxic pollutants in the water column, fish tissue and sediments; and biological evaluation of benthic community data (VADEQ 2002c). Benthic community assessments are, therefore, used to determine compliance with the General Criteria section of Virginia's Water Quality Standards (9 VAC 25-260-20). In general, the stream reach that a biomonitoring station represents is classified as impaired if the RBP ranking is either moderately or severely impaired.

Biomonitoring data collected by VADEQ on Smith Creek and by the U.S. Forest Service (USFS) on Mountain Run and Fridley Run indicate an impairment of the benthic macroinvertebrate community in these streams. The 1998 303(d) Fact Sheet for Smith Creek lists organic enrichment and solids deposition from agricultural runoff as the likely impairment sources. The 2002 303(d) Fact Sheets for Mountain Run and Fridley Run list atmospheric deposition as the likely source of impairment (low pH conditions).

Sediment TMDLs were developed for Smith Creek, based on an analysis of potential benthic macroinvertebrate community stressors and the use of a reference watershed approach. The stressor analysis also covered Mountain Run and Fridley Run and identified low pH/acidity as the primary cause of impairment in these streams. Further analysis is needed to characterize the source of low pH conditions in Mountain Run and Fridley Run and develop an appropriate TMDL methodology to address this problem. Therefore, TMDLs for Mountain Run and Fridley will be addressed in a separate TMDL report.

SECTION 2

WATERSHED CHARACTERIZATION AND MONITORING SUMMARY

2.1 Watershed Characterization

2.1.1 General Information

The Smith Creek watershed (Virginia Waterbody Identification Code, VAV-B47R) is located in the Potomac River Basin in Shenandoah and Rockingham counties, with a small portion of the headwaters located in the City of Harrisonburg, Virginia (USGS Hydrologic Unit Code, 02070006) (Figure 1.1). The Smith Creek watershed is approximately 67,900 acres in size and land use is predominantly forest and agricultural.

2.1.2 Geology

The Smith Creek watershed is located in the Shenandoah Valley of Virginia, which is part of the Valley and Ridge physiographic province. The Valley and Ridge physiographic province is a belt of folded and faulted clastic and carbonate sedimentary rocks situated west of the Blue Ridge crystalline rocks and east of the Appalachian Plateaus. The Shenandoah Valley makes up part of the Great Valley subprovince, which extends from New York southwest to Alabama. This area is characterized by broad valleys with low to moderate slopes underlain by carbonate rocks. Limestone and dolomite (which are carbonate rocks) occur beneath the surface forming the most productive aquifers in Virginia's consolidated rock formations. The gently rolling lowland of the valley floor lies at an elevation of approximately 1000 feet above sea level. Sinkholes, caves, and caverns are common in the valley due to its karst geology.

2.1.3 Soils

Soils data were obtained from the State Soil Geographic (STATSGO) database which includes general soils data and map unit delineations for the United States. GIS coverages provide accurate locations for the soil map units (MUIDs) at a scale of 1:250,000 (NRCS 1994). A map unit is composed of several soil series having similar properties. The following soil series descriptions are based on NRCS Official Soil Descriptions (1998-2002).

STATSGO Soil Type VA001 is composed of the Berks and Weikert series. The Berks series

accounts for most of the map unit and consists of moderately deep, well drained soils formed in residuum weathered from shale, siltstone and fine grained sandstone on rounded and dissected uplands. Permeability is moderate or moderately rapid and slopes range from 0 to 80 percent.

STATSGO Soil Type VA002 is composed of the Carbo, Chilhowie, Frederick, and Lowell series. The Carbo series and the Chilhowie series account for most of the map unit. Both the Carbo and Chilhowie series consist of moderately deep, well drained, and slowly permeable soils. The Carbo series are formed in material weathered from limestone bedrock. These soils are located on nearly level to very steep soils on uplands in the Appalachian Ridges and Valleys. Slopes range from 2 to 65 percent. Chilhowie soils are formed in residuum from interbedded shale and limestone. Slopes range from 0 to 60 percent.

STATSGO Soil Type VA003 is composed of the Frederick and Carbo series. The Frederick series accounts for most of the map unit. This series consists of very deep, well drained soils formed in residuum derived mainly from dolomitic limestone with interbeds of sandstone, siltstone, and shale. These soils are on nearly level to very steep uplands and slopes range from 0 to 66 percent. Permeability is moderate.

STATSGO Soil Type VA004 is composed of the Moomaw, Jefferson, and Alonzville series. The Moomaw series accounts for most of the map unit and consists of very deep, moderately well drained, slowly or moderately slowly permeable soils on stream terraces. These soils have a fragipan and are formed in alluvium derived from acid sandstone, quartzites, and shales. Slopes range from 0 to 30 percent.

STATSGO Soil Type VA005 is composed of the Wallen and Dekalb series. The Wallen series is the dominant series in the map unit. The Wallen series consists of moderately deep, somewhat excessively drained soils that formed in residuum or colluvium and residuum weathered from fine-grained sandstone, siltstone, and shale. These soils are found on mountaintops and on mountain sides that are dominantly south and west facing. Slopes range from 2 to 85 percent.

2.1.4 Climate

The area's climate is typical of other regions in the Shenandoah Valley. Weather data for the Smith Creek watershed can be characterized using the Timberville 3 E meteorological station (NCDC), which is located approximately 1.89 miles west of the watershed (period of record: 1948-1990). The growing season lasts from May 5 through October 10 in a typical year (SERCC 2003). Average annual precipitation is 35.48 inches with August having the highest average precipitation (3.90 inches). Average annual snowfall is 22.9 inches, most of which occurs in January and February. The average annual maximum and minimum daily temperature is 65.8°F and 41.7°F, respectively. The highest monthly temperatures are recorded in July (86.6°F - avg. maximum) and the lowest temperatures are recorded in January (21.8°F - avg. minimum).

2.1.5 Land Use

General land use/land cover data for the Smith Creek watershed were extracted from the Multi-Resolution Land Characterization (MRLC) database for the state of Virginia (USEPA 1992) and is shown in Figure 2.1. This database was derived from satellite imagery taken during the early 1990s and is the most current detailed land use data available. Land uses in the Smith Creek watershed include various urban, agricultural, and forest categories (Table 2.1 and Figure 2.1). Approximately 50% of the watershed is forested, while approximately 47% of the watershed is used for agricultural purposes. Residential and commercial development account for less than 4% of the watershed.

Table 2.1 MRLC and consolidated land uses in the Smith Creek watershed

MRLC Land Use	Area (acres)	Percent	Consolidated Land Use	Area (acres)	Percent
Woody Wetlands	1.9	0.01%	Forest	13,597.1	49.5%
Emergent Herbaceous Wetlands	15.2	0.06%			
Deciduous Forest	10,537.0	38.35%			
Evergreen Forest	559.1	2.03%			
Mixed Forest	2,483.9	9.04%			
Open Water	40.8	0.15%	Water	40.8	0.1%
Pasture/Hay	11,730.2	42.69%	Pasture/Hay	11,730.2	42.7%
Row Crops	1,074.9	3.91%	Cropland	1,074.9	3.9%
Transitional	64.2	0.23%	Transitional	64.2	0.2%
Other Grasses (Urban/recreational)	51.2	0.19%	Urban	970.8	3.5%
High Intensity Residential	9.9	0.04%			
Low Intensity Residential	520.5	1.89%			
High Intensity Commercial/Industrial/Transportation	162.4	0.59%			
High Intensity Residential-Impervious	6.6	0.02%			
High Intensity Commercial/Industrial/Transportation-Impervious	162.4	0.59%			
Low Intensity Residential-Impervious	57.8	0.21%			
Total	27,478.0	100.00%	Total	27,478.0	100.0%

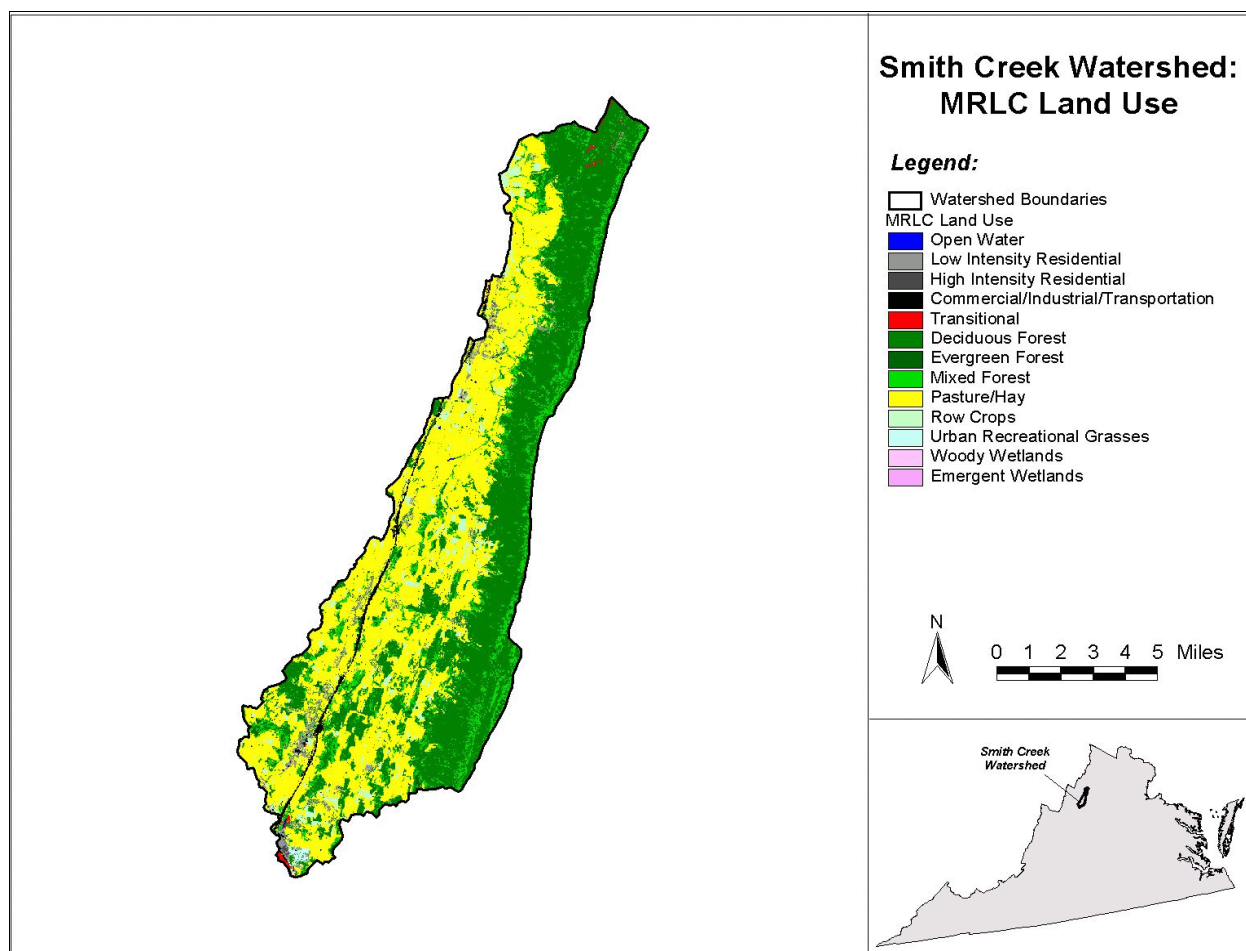


Figure 2.1 MRLC land use in the Smith Creek watershed

2.1.6 Ecoregion

The Smith Creek watershed is located in the Central Appalachian Ridges and Valleys ecoregion - Level III 67 (Woods et al. 1999). This ecoregion is a northeast-southwest trending, relatively low-lying, but diverse ecoregion, sandwiched between generally higher, more rugged mountainous regions with greater forest cover. As a result of extreme folding and faulting events, the region's roughly parallel ridges and valleys have a variety of widths, heights, and geologic materials, including limestone, dolomite, shale, siltstone, sandstone, chert, mudstone, and marble. Springs and caves are relatively numerous. Present-day forests cover about 50% of the region. The ecoregion has a diversity of aquatic habitats and species of fish.

At a finer scale, the Smith Creek and Mountain Run watersheds are located in the Northern Limestone/Dolomite Valleys and Northern Sandstone Ridges subcoregions - Level IV classifications 67a and 67c respectively (Woods et al. 1999). The Fridley Run watershed is located in the Northern Sandstone Ridges subcoregion. The Northern Limestone/Dolomite Valleys is a

lowland ecoregion characterized by broad, level to undulating, fertile valleys that are extensively farmed. Sinkholes, underground streams, and other karst features have developed in the underlying limestone/dolomite, and as a result drainage density is low. Where streams occur, they tend to have gentle gradients, plentiful year round flow, and distinctive fish assemblages. Silurian, Ordovician, and Cambrian limestone and dolomite commonly underlie the region. Interbedded with the carbonates are other rocks, including shale, which give the ecoregion topographic and soil diversity. Local relief typically ranges from 50 to 500 feet.

The Northern Sandstone Ridges ecoregion is characterized by high, steep, forested ridges with narrow crests. High-gradient streams flow off the ridges into narrow valleys. Streams do not have as much buffering as other local ecoregions and are subject to acidification. The ridges of the region are composed of folded, interbedded sandstone and conglomerate. Less resistant rocks, such as shale and siltstone, may form the side slopes. Crestal elevations range from about 1,000 to 4,300 feet and local relief typically ranges from 500 to 1,500 feet.

2.2 Stream Characterization

Smith Creek flows north from its headwaters to its confluence with the North Fork Shenandoah River. Smith Creek flows predominantly thorough pasture/hay and forest lands. There is a transition in stream gradient and substrate type between the upper and lower portions of the watershed. Mountain Run and Fridley Run are located in high gradient sandstone geology; whereas, Smith Creek and Dry Fork are located in lower gradient limestone/dolomite geology. Streams in the lower watershed flow through large expanses of pasture land and are utilized for livestock watering in some areas and other agricultural production activities.

2.3 Water Quality and Biomonitoring Summary

2.3.1 Monitoring Stations

There are thirteen current and historical VADEQ water quality monitoring stations located in the Smith Creek watershed. Biomonitoring data collected at the VADEQ stations 1BSMT005.71 and 1BSMT006.62 on Smith Creek, VADEQ station 1BLAC000.14 on Lacey Spring Branch, and several U.S. Forest Service (USFS) stations on Mountain Run and Fridley Run. Data from these biomonitoring stations were used to assess Smith Creek, Mountain Run, and Fridley Run as impaired. As part of the benthic TMDL study, George Mason University (GMU) personnel conducted water quality and biomonitoring at thirteen stations on Smith Creek, Mountain Run, and Fridley Run. Several of the GMU stations are co-located with VADEQ monitoring stations. VADEQ, USFS, and GMU monitoring stations located in the Smith Creek watershed are presented in Table 2.2 and shown in Figure 2.2. The water quality data periods shown in Table 2.2 include field parameters collected during biomonitoring site visits.

Table 2.2 Monitoring stations in the Smith Creek watershed

Station	Organization	Station Type	Location	Data Period
1BSMT001.42	VADEQ	WQ	Rt. 730 bridge	No data available
1BSMT004.60	VADEQ	WQ	Rt. 620 bridge	1/18/90 - 6/2/03 (Samples not incl. in this report: 4/23/79 – 12/5/89 & 8/6/03 – 10/23/03)
1BSMT005.71	VADEQ	Bio	Down stream of Rt. 620 bridge	10/5/94 - 10/20/98 (after 1998, this station was moved to 1BSMT006.62 due to bridge reconstruction)
1BSMT006.62	VADEQ	Bio	Rt. 620 bridge	5/18/99 – 9/27/01
1BSMT010.90	VADEQ	WQ	Rt. 211 bridge	3/3/70 - 2/22/79
1BSMT018.40	VADEQ	WQ	Rt. 798 bridge	3/3/70 - 6/12/74
1BSMT023.18	VADEQ	WQ	Rt. 608 bridge	12/18/91 - 6/4/01
1BSMT028.00	VADEQ	WQ	Rt. 806 bridge	7/26/01 - 5/27/03
1BSMT031.69	VADEQ	WQ	Rt. 724 bridge	7/26/01 - 5/27/03
1BMTR000.93	VADEQ	WQ, SS	Mountain Run, Rt. 620 bridge	6/30/2003 (Samples not incl. in this report : 7/24/03 – 10/27/03)
1BFDY000.02	VADEQ	WQ, SS	Fridley Run, At Fridley Gap in GW National Forest	6/30/2003 (Samples not incl. in this report : 7/24/03 – 10/27/03)
1BDFK000.76	VADEQ	WQ	Dry Fork, Rt. 806 bridge	7/30/01 - 5/27/03
1BLAC000.14	VADEQ	Bio	Lacey Spring Branch, Just upstream of Rt. 81 culvert	Samples not incl. in this report: 8/8/00 & 3/23/01
4015	USFS	WQ	Mountain Run	10/2/92 – 12/11/96
4070	USFS	WQ	Mountain Run	No data available
4071	USFS	WQ	Fridley Run	10/2/92 – 12/11/96
4072	USFS	WQ	Mountain Run	10/2/92 – 12/11/96
4073	USFS	WQ	Mountain Run	10/2/92 – 12/11/96
4074	USFS	WQ, Bio	Fridley Run	10/2/92 – 12/11/96, 1/30/2002 (WQ only); 5/10/01 (Bio only)
4076	USFS	WQ, Bio	Mountain Run	1/30/2002 (WQ only); 5/18/00 & 5/10/01 (Bio only)
4080	USFS	WQ	Fridley Run	11/3/92-12/11/96
Smith1	GMU	WQ, Bio	At 616/USGS gauge (DEQ 4.60)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith1A	GMU	WQ, Bio	At Rt. 620 (DEQ 6.62)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith2	GMU	WQ, Bio	At Rt. 794	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith3	GMU	WQ, Bio	At Rt. 798 (Arkton Rd.)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith3A	GMU	WQ	At Rt. 620 (7157) (DEQ 5.71)	4/25/03 (WQ only)
Smith4	GMU	WQ, Bio	At Rt. 608 (Mauzy-Athlone Rd.)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith5	GMU	WQ, Bio	Dry Fork, At Rt. 11S (near 721)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)

TMDL Development for Smith Creek

Station	Organization	Station Type	Location	Data Period
Smith6	GMU	WQ, Bio	At Rt. 724 near 717 (Fluke Rd.)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith7	GMU	WQ, Bio	Mt. Run @ Mt. Valley Rd. (100 ft. from Rt. 811 (Fridley Gap Rd.))	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith8	GMU	WQ, Bio	Fridley Run just above confl w/Mtn. Run extended (George Washington Forest)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
Smith9	GMU	WQ, Bio	Mt. Run extended just above confl w/Fridley Run (George Washington Forest)	5/29/03, 10/5-10/6/03 (WQ & Bio); 7/25/03 (Bio only)
MtnRun1 (not in Figure 2.2)	GMU	WQ	At trailhead; at Rt. 620 (USFS 4015)	4/25/03 (WQ only)
MtnRun2 (not in Figure 2.2)	GMU	WQ	At Rt. 620 (Fridley Gap Rd.)	4/25/03 (WQ only)

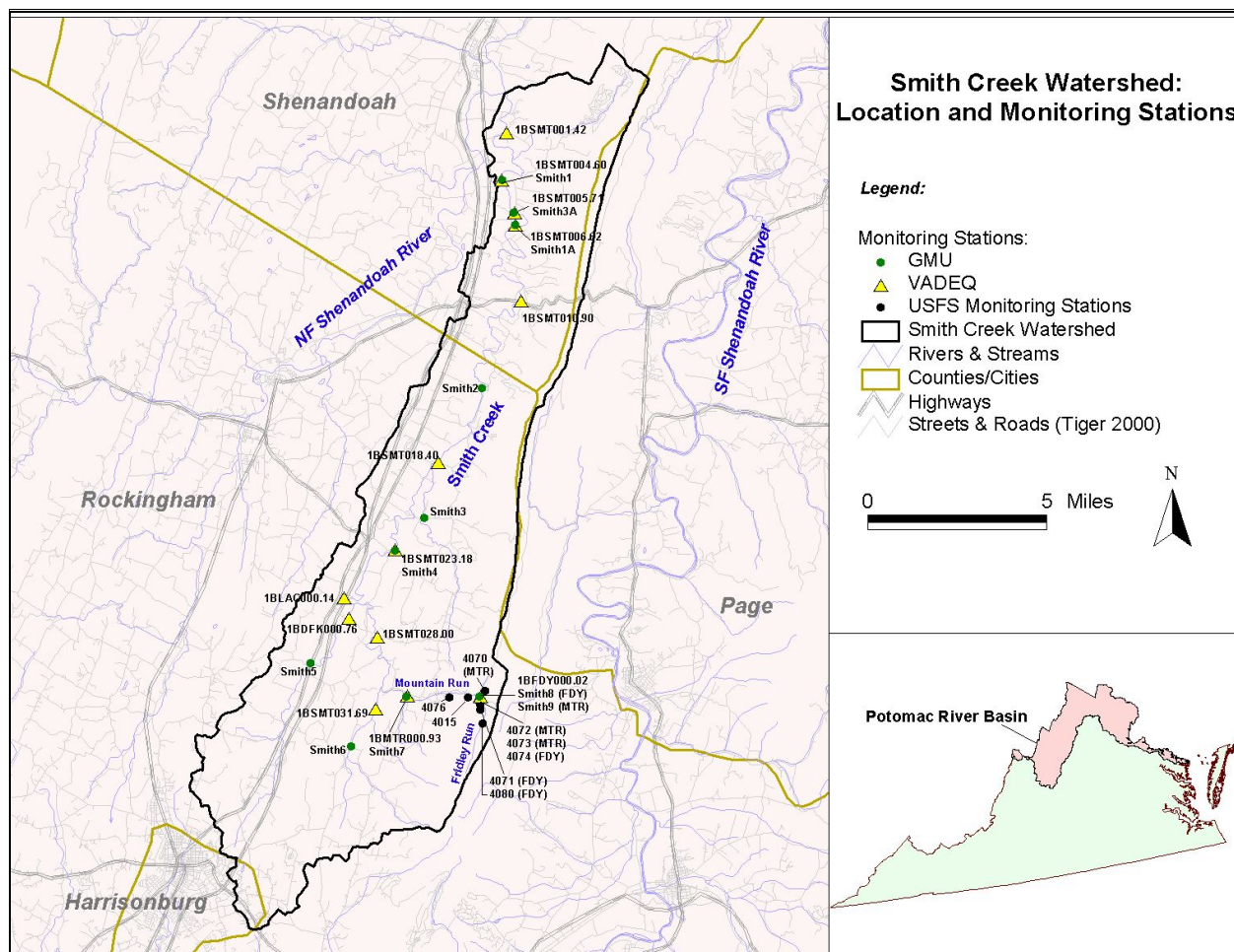


Figure 2.2 Location of Smith Creek, Mountain Run, and Friddle Run monitoring stations

2.3.2 Fecal Coliform Bacteria and *E. coli* Data

Data collected by VADEQ from 1/18/90 through present were compared to the new instantaneous and geometric mean criteria for fecal coliform bacteria and *E. coli*. Bacteria Source Tracking (BST) data were also collected by VADEQ at station 1BSMT004.60 from 5/6/03 through 10/27/03. These data were also included in the following analysis. The results of the BST study are presented in Section 2.3.3.

The bacteria data collected at each VADEQ monitoring station are summarized in Table 2.3.

Table 2.3 Bacteria monitoring summary

Station	Date	Sample Type ¹	Count	Min-Max	Instantaneous Criteria FC: 400 cfu EC: 235 cfu (% Violations)
1BSMT004.60 (Smith Creek)	1/18/90 -12/29/03	FC	139	25-8,000	27
	8/5/02 -12/29/03	EC	15	20-820	40
1BSMT023.18 (Smith Creek)	12/18/91 - 6/4/01	FC	42	100-8,000	57
		EC	no data		
1BSMT028.00 (Smith Creek)	1/22/02 - 5/30/02	FC	12	100-900	33
		EC	no data		
1BSMT031.69 (Smith Creek)	7/26/01 - 5/27/03	FC	12	100-1,300	33
		EC	no data		
1BDFK000.76 (Dry Fork)	7/30/01 - 5/27/03	FC	11	100-8,000	73
		EC	no data		
1BMTR000.93 (Mountain Run)	6/30/03 - 10/27/03	FC	5	25-380	20
		EC	no data		
1BFDY000.02 (Fridley Run)	6/30/03 - 10/27/03	FC	5	25-320	0
		EC	no data		

¹ Sample type: FC = Fecal Coliform Bacteria, EC = *E. coli*

Several samples had a fecal count of 8,000 cfu/100 ml. The upper limit of laboratory analysis was typically 8,000 cfu/100 ml, depending on collection date. Therefore, many of these samples likely represent concentrations much higher than these limits. The percent violation analysis provides insight into the magnitude of the fecal contamination problems in these streams. Violations occurred in all flow regimes.

2.3.3 Bacteria Source Tracking (BST)

VADEQ collected BST data at station 1BSMT004.60 from 5/6/03 through 10/27/03 (6 monthly samples) to help identify the predominant sources of bacteria in the watershed (Table 2.4). Fecal coliform bacteria and *E. coli* concentrations were measured and the Antibiotic Resistance Analysis (ARA) methodology was used to determine the likely sources of bacteria in each sample. This methodology provides information on the presence or absence of human, pet, livestock, and wildlife sources in the watershed. No information was provided for upstream areas of the watershed.

Table 2.4 BST results for Station 1BSMT004.60

Date	Fecal concentration (cfu/100ml)	<i>E. coli</i> concentration (cfu/100ml)	Wildlife (%)	Human (%)	Livestock (%)	Pets (%)
5/6/03	300	270	13	4	62	21
6/30/03	3,600	340	45	0	13	42
7/21/03	580	340	21	4	75	0
8/11/03	5,400	820	46	0	64	0
9/15/03	250	210	29	0	46	25
10/27/03	140	108	25	0	67	8

* bold values were statistically significant

2.3.4 Biomonitoring Data

VADEQ currently uses the EPA Rapid Bioassessment Protocol (RBP II method) to determine the impairment status of monitored streams based on comparisons to reference streams. VADEQ stations 1BSMT005.71 and 1BSMT006.62 on Smith Creek were sampled on several occasions from 1994 through 2001. USFS stations 4074 and 4072 on Fridley Run were sampled from 1992 through 2001 and 1992 through 1996, respectively. USFS station 4015 on Mountain Run was sampled from 1992 through 1996. These data indicated a moderate impairment of the benthic macroinvertebrate community on each stream, which resulted in the impairment listing.

2.3.5 Virginia Stream Condition Index (VaSCI)

Available biomonitoring data were summarized to help characterize the benthic community in the Smith Creek watershed. The Virginia Stream Condition Index (VaSCI) was used to assess the biological community in each stream. The benthic multimetric scores provided by this index allow for a more detailed and reliable assessment of the benthic macroinvertebrate community in Virginia's non-coastal, wadeable streams (USEPA 2003). VADEQ and GMU biomonitoring data were used to calculate the VaSCI score for each station (Table 2.5). Data for GMU sampling sites are included in the scores based on correspondence with VADEQ station locations. The VaSCI scores for Smith Creek, Mountain Run, and Fridley Run were less than the recommended impairment threshold of 61 on several occasions. These scores were also lower than comparable scores at several reference stations in the region.

Table 2.5 VaSCI standardized scores for Smith Creek, Mountain Run, and Fridley Run

StationID	Organization	Stream	Location	Sample Date	VaSCI Index Score
SMT005.71	DEQ	Smith Creek	Downstream of Rt. 620 bridge	10/05/1994	52
				05/22/1995	72
				09/28/1995	64
				05/23/1996	57
				05/27/1997	56
				09/23/1997	63
				10/20/1998	71
Average					62
SMT006.62	DEQ	Smith Creek	Rt. 620 bridge	05/18/1999	60
				10/14/1999	68
				04/17/2000	57
				11/02/2000	71
				09/27/2001	48
Smith1A	GMU	Smith Creek		05/29/2003	44
Average					58
Smith1	GMU	Smith Creek	At Rt. 616, DEQ station 1BSMT004.60	05/29/2003	56
Smith2	GMU	Smith Creek	At Rt. 794	07/25/2003	45
Smith4	GMU	Smith Creek	At Rt. 608, DEQ station 1BSMT023.18	07/25/2003	41
Smith7	GMU	Mountain Run	At Mt. Valley Rd.	05/29/2003	53
Smith8	GMU	Fridley Run	Just above confluence w/Mountain Run ext.	05/29/2003	53
Smith9	GMU	Mountain Run ext.	Just above confluence w/Fridley Run	05/29/2003	70
Overall Average					58

SECTION 3

SOURCE ASSESSMENT - BACTERIA

Point and nonpoint sources of bacteria in the Smith Creek watershed were considered in TMDL development. The source assessment was used as the basis of model development and analysis of TMDL allocation options. A variety of information was used to characterize sources including, agricultural and land use information, water quality monitoring and point source data, GIS coverages, past TMDL studies, literature sources, and other information. Procedures and assumptions used in estimating bacteria loads are described in the following sections.

3.1 Assessment of Nonpoint Sources

Agricultural runoff and wildlife are listed as the primary sources of bacteria, according to the 2002 303(d) Fact Sheet for Smith Creek. Nonpoint sources of bacteria can include failing septic systems and leaking sewer lines, straight pipes, livestock (including manure application loads), wildlife, and domestic pets. The representation of the following sources in the model is discussed in Section 4.

3.1.1 Septic Systems and Straight Pipes

Residential septic systems treat human waste using a collection system that discharges liquid waste into the soil through a series of distribution lines that comprise the drain field. Fecal coliform bacteria naturally die-off as the effluent percolates through the soil to the groundwater. These systems effectively remove fecal coliform bacteria when properly installed and maintained.

A septic system failure occurs when there is a discharge of waste to the soil surface where it is available for washoff into surface waters. Failing septic systems can deliver high bacteria loads to surface waters, depending on the proximity of the discharge to a stream and the timing of rainfall events. Septic system failures typically occur in older systems that are not adequately maintained with periodic sewage pump-outs.

An estimated 7,227 people live in houses with a septic system or other means of sewage disposal (e.g., straight pipe) in the Smith Creek watershed, as determined using the following methods. U.S. Census block-group data for Year 2000 were used to estimate the population served by sewer systems, septic systems, and other means (Census 2000). The septic population was determined based on the area of the Smith Creek watershed that is located within each census block-group.

The number of failing septic systems was estimated using a failure rate of 4% based on information

provided by the Virginia Department of Health (Kelly Vanover, VDH, pers. comm. 2004). A fecal coliform bacteria concentration of 10^5 cfu/100mL and a septic system waste flow of 70 gallons/person/day was used to estimate the contribution from failing septic systems to surface waters (Metcalf and Eddy, Inc. 1991). In some cases, human waste is directly deposited into surface waters from houses without septic systems. These “straight pipes” and other illicit discharges are illegal under Virginia regulations. Houses with straight pipes are typically older structures that are located in close proximity to a stream. The population served by straight pipes was assumed to be 0.5% of the septic population in the watershed (Kelly Vanover, VDH, pers. comm. 2004). Houses considered to have a normal functioning septic system were assumed to have a negligible contribution of fecal coliform bacteria to surface waters.

3.1.2 Livestock

Animal population estimates for dairy cattle and poultry (chickens and turkeys) were based on combined animal feeding operation (CAFO) data for the Smith Creek watershed provided by the Virginia Department of Conservation and Recreation (VADCR) (Table 3.1). Livestock population data for horses, hogs/pigs, and sheep/lambs were obtained from the 1997 Virginia Agricultural Census data for Shenandoah and Rockingham Counties (VASS 1997). For the 1997 Agricultural Census data, a weighted average was used to estimate the population of each livestock species based on the percentage of pasture/hay land in the watershed (Table 3.1). Other livestock animals had very small populations as compared to the major livestock species listed in the table; therefore, the bacteria loads from these animals were assumed to be negligible.

Table 3.1 Livestock population estimates

Livestock Species	Smith Creek Population
Beef Cattle	3,923
Dairy Cattle	1,475
Horses	194
Hogs/Pigs	570
Sheep/Lambs	972
Chickens (pullets, layers, and broilers)	963,300
Turkeys	945,700

Bacteria produced by livestock can be deposited on the land, directly deposited in the stream (as is common when grazing animals have stream access), manually applied to cropland and other agricultural lands as fertilizer, or contributed to surface waters through illicit discharges from animal confinement areas. Bacteria deposited on the land, either directly or through manure application, are available for washoff into surface waters during rainfall events. There are no known illicit discharges of animal waste in the watershed.

Grazing animals, such as beef and dairy cattle, typically spend portions of the day confined to loafing lots, grazing on pasture lands, and watering in nearby streams. The percentage of time spent in each area effects the relative contribution of bacteria loads to the stream. The amount of time beef and dairy cattle spend in or near streams primarily depends on time of year and the availability of stream access and off-stream watering facilities. Estimates of the amount of time cattle spend in these different areas were based on the results of a recent study conducted by VADCR entitled *Modeling Cattle Stream Access* (VADCR 2002) and watershed modeling results. Cattle data are presented in Tables 3.2 and 3.3. Beef cattle typically spend more time grazing in open areas than dairy cattle, which are confined for milking several hours a day. Horse and sheep estimates were based on similar past TMDL studies. Horses were assumed to spend the majority of each day in pasture (75% of the day in pasture during March - November, 25% in December - February). Sheep were assumed to be in pasture 100% of the time.

Table 3.2 Beef cattle - daily hours spent grazing, in confinement, and in streams

Month	Grazing (hours)	Loafing Lot - Confinement (hours)	Stream Access (hours)
January	4.7	19.2	0.02
February	4.7	19.2	0.02
March	14.3	9.6	0.06
April	14.3	9.6	0.09
May	14.3	9.6	0.09
June	14.3	9.6	0.1
July	14.3	9.6	0.1
August	14.3	9.6	0.1
September	14.3	9.6	0.09
October	14.3	9.6	0.06
November	14.3	9.6	0.06
December	4.8	19.2	0.01

Table 3.3 Dairy cattle - daily hours spent grazing, in confinement, and in streams

Month	Grazing (hours)	Loafing Lot - Confinement (hours)	Stream Access (hours)
January	2.4	21.1	0.5
February	2.4	21.1	0.5
March	3.5	19.7	0.8
April	5.5	17.3	1.2

Month	Grazing (hours)	Loafing Lot - Confinement (hours)	Stream Access (hours)
May	6.4	16.2	1.4
June	6.9	15.6	1.5
July	7.6	14.8	1.6
August	7.6	14.8	1.6
September	7.7	14.8	1.5
October	7.3	15.4	1.3
November	6.4	16.5	1.1
December	4.7	18.5	0.8

Collected manure from livestock animals was applied to cropland and pasture in the Smith Creek watershed based on manure application information obtained in past valley TMDL studies. The majority of the manure collected was applied to cropland (75%) in spring and fall months. A small percentage of the manure collected was applied to pastureland areas in the winter and summer months. Cattle and poultry manure represent the primary sources of land-applied livestock waste. Turkeys and chickens are confined to poultry houses and hogs are confined to feed lots in the watershed; therefore, all litter produced is manually applied to cropland and pasture. The application of collected manure for these species follows the schedule in listed in Table 3.4. The manure is used to fertilize corn and other primary crops in the spring and winter wheat in the fall. Tillage allows for the incorporation of fecal coliform bacteria that is applied to the soil surface. Based on field observations of cropland in the watershed and past TMDL studies, it was assumed that 25% of the manure that was applied was incorporated into the soil, resulting in 75% of the fecal coliform bacteria load being available for washoff.

Table 3.4 Livestock - fraction of the annual manure application that is applied each month

Month	Livestock Manure Fraction Applied
January	0
February	0
March	0.075
April	0.16
May	0.13
June	0.13
July	0.13

Month	Livestock Manure Fraction Applied
August	0.13
September	0.16
October	0.075
November	0
December	0

Fecal coliform bacteria production rates used for livestock species in the Smith Creek watershed are listed in Table 3.5. A variety of sources were consulted to determine the appropriate daily fecal coliform bacteria production value for each species, including other valley TMDL studies and literature sources.

Table 3.5 Livestock fecal coliform bacteria production rates

Livestock Species	Daily Production (cfu/animal/day)	Primary Sources
Beef cattle	4.46×10^{10}	ASAE 1998, USGS 2002
Dairy cattle	3.90×10^{10}	ASAE 1998, USGS 2002
Chickens	6.75×10^7	ASAE 1998, USGS 2002
Turkeys	9.30×10^7	ASAE 1998, USGS 2002
Hogs/Pigs	1.08×10^{10}	ASAE 1998, USGS 2002
Sheep	1.96×10^{10}	ASAE 1998, USGS 2002
Horses	5.15×10^{10}	ASAE 1998, USGS 2002

3.1.3 Wildlife

Wildlife species in the watershed were identified through consultation with the Virginia Department of Game and Inland Fisheries (VDGIF). The predominant species include ducks, geese, deer, beaver, raccoon, and muskrat. The population of each wildlife species was estimated using the population density per square mile of habitat area and the total area of suitable habitat in the watershed (Table 3.6). Habitat areas were determined using GIS and the watershed land use coverage (MRLC). The density and habitat assumptions used to estimate the population of each wildlife species were updated based on information provided by state and local VDGIF personnel. Population estimates and the defined habitat of each species in the Smith Creek watershed are listed in Table 3.7. Percent time spent in streams was adjusted based on recent valley TMDL studies and watershed model calibration data.

Table 3.6 Wildlife population density by land use (# animals per square mile of habitat)

Land Use	Ducks		Geese		Deer	Beaver	Raccoon	Muskrat
	Summer	Winter	Summer	Winter				
Cropland	30	40	50	70	0	5	2.5	320
Pasture/Hay	30	40	50	70	35	5	2.5	160
Forest	10	20	0	0	35	10	5	160
Built-Up (Urban)	30	40	50	70	0	5	2.5	320

Table 3.7 Wildlife habitat descriptions, population estimates, and percent of time spent in streams

Wildlife Species	Habitat Description	# of Animals	% in Streams
Ducks	100 meter buffer around perennial streams for all land uses	173 in summer 253 in winter	2.5%
Geese	100 meter buffer around perennial streams for Pasture/Hay, Cropland, and Built-Up	235 in summer 329 in winter	2.5
Deer	25 deer/mi ² for Pasture and Forest	3,429 year-round	1
Beaver	20 meter buffer around perennial streams for all land uses	12 year-round	50
Raccoon	0.5 mile buffer around perennial streams for all land uses	172 year-round	1
Muskrat	20 meter buffer around perennial streams for all land uses	267 year-round	2.5

As with grazing livestock, wildlife deposit on the land and directly to surface waters. The percentage of fecal coliform bacteria that was directly deposited to surface waters was estimated based on the habitat of each species. The remaining fecal coliform load was applied to the upland landuses, according to the total area of each landuse within established habitat areas. The typical fecal coliform density for each wildlife species was used to calculate fecal coliform bacteria loads (Table 3.8).

Table 3.8 Fecal coliform bacteria production rates for wildlife species

Wildlife Species	Daily Production (cfu/animal/day)	Primary Sources
Ducks	7.35×10^9	ASAE 1998, USGS 2002
Geese	7.99×10^8	USGS 2002
Deer	3.47×10^8	VADEQ 2001
Beaver	2.0×10^5	VADEQ 2000
Raccoon	5.0×10^9	VADEQ 2001
Muskrat	2.5×10^7	VADEQ 2001

3.1.4 Domestic Pets

Domestic pets were also considered in source assessment and watershed modeling. The bacteria contribution from domestic pets was represented by the waste deposited by dogs. The contribution from other pets was considered negligible. Housing estimates were used to determine the number of dogs in the watershed (Census 2000). Based on the assumption of one dog per household, the number of dogs in the Smith Creek watershed was estimated to be approximately 2,687. The fecal coliform concentration in dog waste is 1.85×10^9 cfu/100mL (Mara and Oragui 1981).

3.2 Assessment of Point Sources

Point sources, such as municipal sewage treatment plants, can contribute fecal coliform bacteria loads to surface waters through effluent discharges. These facilities are permitted through the Virginia Pollutant Discharge Elimination System (VPDES) program that is managed by VADEQ. There are currently 38 point source permits in the Smith Creek watershed (Table 3.9), including a Municipal Separate Storm Sewer System (MS4) permit that was issued to the City of Harrisonburg to help control impacts caused by stormwater runoff from urban areas (VPDES # VAR040075). The bacteria load contributed by the MS4 permit during runoff events was calculated based on the modeling results for urban lands located within the City of Harrisonburg and the Smith Creek watershed. The bacteria load contributed by all other facilities was calculated based on the permitted flow (1,000 gallons/day for general permits) and the applicable *E. coli* limit (126 cfu/100ml, geometric mean concentration).

* Note that the following permits do not discharge bacteria and were not included in the bacteria TMDL for Smith Creek: VA0091235, VAG110131, VAR100591, VAR102386, and VAR051331.

Table 3.9 VPDES permitted facilities in the Smith Creek watershed

VPDES Permit No.	Facility Name	Receiving Stream
VA0027626	Valley View Mobile Home Court	Dry Fork X Trib
VA0054453	New Market Poultry Products	Smith Creek
VA0071846	Endless Caverns Inc	Smith Creek X Trib
VA0080535	Two Hills Inc STP	Smith Creek
VA0077399	Lacey Spring Elementary School STP	Lacey Spring, U.T.
VA0090794	Holtzman Express-Mauzy	Smith Creek
VA0091235	Shenandoah Fisheries, Ltd	Lacey Spring
VA0088994	Harrisonburg-New Market KOA	War Branch
VA0083305	Camp Overlook	Mountain Run
VAG408049	Private Residence	Smith Creek, UT
VAG401001	Private Residence	Smith Creek
VAG401128	Private Residence	Smith Creek, U.T.
VAG401201	Private Residence	Smith Creek
VAG401179	Private Residence	Smith Creek, U.T.
VAG401363	Private Residence	Smith Creek, U.T.
VAG401492	Private Residence	Smith Creek, U.T.
VAG401537	Private Residence	Smith Creek, U.T.
VAG401551	Private Residence	Smith Creek, U.T.
VAG401405	Private Residence	Smith Creek, U.T.
VAG401890	Private Residence	War Branch
VAG401956	Private Residence	Smith Creek, U.T.
VAG401966	Private Residence	Smith Creek UT
VAG401961	Private Residence	Smith Creek UT
VAG401805	Private Residence	Smith Creek, U.T.
VAG401920	Private Residence	Smith Creek, UT
VAG401432	Private Residence	Smith Creek
VAG401988	Private Residence	Smith Creek, U.T.
VAG401998	Private Residence	Smith Creek, U.T.
VAG408026	Private Residence	Dry Fork, U.T.
VAG408028	Private Residence	Smith Creek, U.T.
VAG408029	Private Residence	Smith Creek, U.T.
VAG408030	Private Residence	Smith Creek, U.T.
VAG408035	Private Residence	Smith Creek, U.T.
VAG110131	Superior Concrete Central Plant	Quarry in Smith Creek watershed
VAR100591	Rockingham Redi-Mix Inc	Dry Fork, UT
VAR102386	Holtzman Express-Mauzy	Smith Creek, UT
VAR051331	Harper's Lawn Ornaments	Dry Fork, UT
VAR040075	City of Harrisonburg MS4	N/A

SECTION 4

WATERSHED MODELING - BACTERIA

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. The objective of this section is to present the approach taken to develop the linkage between sources and in-stream response for the development of bacteria TMDLs for Smith Creek.

4.1 Modeling Framework Selection

Selection of the appropriate approach or modeling technique required consideration of the following:

- Expression of water quality criteria
- Dominant processes
- Source Integration
- Scale of analysis
- Efficient TMDL scenario evaluation

The applicable criteria for bacteria are presented in Section 1. Numeric criteria require evaluation of magnitude, frequency, and duration. *E. coli* water quality criteria are presented as both an instantaneous maximum standard (235 cfu/100ml) and a geometric mean standard (126 cfu/100ml, minimum of two samples collected within a calendar month period). The approach or modeling technique must permit representation of in-stream concentrations under a variety of flow conditions in order to evaluate critical periods for comparison to these criteria.

The appropriate approach must also consider the dominant processes regarding pollutant loadings and in-stream fate. For the Smith Creek watershed, primary sources contributing to bacteria impairments include an array of nonpoint or diffuse sources as well as discrete direct inputs to the stream either by permitted point source discharges or animal direct deposition to the streams. Loading processes for nonpoint sources or land-based activities are typically rainfall-driven and thus relate to surface runoff and subsurface discharge to a stream.

Key in-stream factors that must be considered include routing of flow, dilution, transport, and fate (decay or transformation) of bacteria. In the Smith Creek watershed, the primary physical process

affecting the transport of bacteria is the die-off rate.

Scale of analysis and waterbody type must also be considered in the selection of the overall approach. The approach should have the capability to evaluate watersheds at multiple scales, and be able to adequately represent the spatial distribution of sources and the delivery processes whereby bacteria are delivered throughout the stream network.

Based on the considerations described above, analysis of the monitoring data, review of the literature, characterization of the bacteria sources, the need to represent source controls to individual sources, and previous modeling experience, the Loading Simulation Program C++ (LSPC) was selected to represent the source-response linkage in the Smith Creek watershed. LSPC, the primary watershed modeling system for the EPA TMDL Toolbox, is currently maintained by the EPA Office of Research and Development in Athens, GA (<http://www.epa.gov/athens/wwqtsc>).

Note that the model predicts fecal coliform bacteria concentrations. *E. coli* bacteria concentrations are estimated using the VADEQ fecal coliform bacteria/*E. coli* translator in order to compare the results to the instantaneous and geometric mean criteria for *E. coli* and develop TMDLs (VADEQ 2003).

4.1.1 Loading Simulation Program C++ (LSPC) Overview

LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. A key data management feature of this system is that it uses a Microsoft Access database to manage model data and weather text files for driving the simulation. The system also contains a module to assist in TMDL calculation and source allocations. For each model run, it automatically generates comprehensive text-file output by subwatershed for all land-layers, reaches, and simulated modules, which can be expressed on hourly or daily intervals. Output from LSPC has been linked to other model applications such as EFDC, WASP, and CE-QUAL-W2. LSPC has no inherent limitations in terms of modeling size or model operations. The Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel.

LSPC was designed to facilitate data management for large-scale or complex watershed modeling applications. The model has been successfully used to model watershed systems composed of over 1,000 subwatersheds at a National Hydrography Dataset (NHD) stream-segment scale. The system is also tailored for source representation and TMDL calculation. The LSPC GIS interface, which is compatible with ArcView shapefiles, acts as the control center for launching watershed model scenarios. This stand-alone interface easily communicates with both shapefiles and an underlying Microsoft Access database, but does not directly rely on either of these main programs. Therefore, once a watershed application is created, it is easily transferable to users who may not have ArcView

or MS Access installed on their computers.

Selected HSPF modules were re-coded in C++ and included in the LSPC model. LSPC's algorithms are identical to those in HSPF. Table 4.1 presents the modules from HSPF that are incorporated in LSPC. The user may refer to the Hydrologic Simulation Program FORTRAN User's Manual for a more detailed discussion of simulated processes and model parameters (Bicknell et al. 1996).

Table 4.1 HSPF modules available and supported in the LSPC watershed model

Simulation Type	HSPF Module	HSPF Module Description
Land Based Processes	PWATER	Water budget for pervious land
	IWATER	Water budget for impervious land
	SNOW	Incorporates snow fall and melt into water budget
	SEDMNT	Production and removal of sediment
	PWTGAS	Est. water temperature, dissolved gas concentrations
	IQUAL	Simple relationships with solids and water yield
	PQUAL	Simple relationships with sediment and water yield
In-stream Processes	HYDR ADCALC	Hydraulic behavior, pollutant transport
	CONS	Conservative constituents
	HTRCH	Heat exchange, water temperature
	SEDTRN	Behavior of inorganic sediment
	GQUAL	Generalized quality constituent

Meteorological Data Processing

Weather conditions are the driving force for watershed hydrology processes. For the simulation options selected for the Smith Creek watershed model, the required parameters include hourly precipitation and hourly potential evapotranspiration. Precipitation is measured, while potential evapotranspiration is empirically computed using temperature and gage latitude. Table 4.2 below summarizes the weather data that were collected for the Smith Creek watershed model. These data were obtained from the listed National Climatic Data Center (NCDC) meteorological stations.

Table 4.2 NCDC meteorological datasets compiled for the Smith Creek watershed model

Station ID	Timestep	Data Type	Station Name	Start Date	End Date	Elevation (ft)
VA2208	Hourly	Precipitation	Dale Enterprise	9/1/1978	12/31/2002	1000
449263	Daily	Precipitation	Woodstock 2 NE	1/1/1930	12/31/2002	680
449263	Daily	Min Temperature	Woodstock 2 NE	1/1/1930	12/31/2002	680
449263	Daily	Max Temperature	Woodstock 2 NE	1/1/1930	12/31/2002	680
442663	Daily	Precipitation	Edinburg	6/1/1996	12/31/2002	840
442663	Daily	Min Temperature	Edinburg	6/1/1996	12/31/2002	840
442663	Daily	Max Temperature	Edinburg	6/1/1996	12/31/2002	840

There were no NCDC monitoring stations located within the Smith Creek watershed. The nearest hourly station is Dale Enterprise (VA2208), which is approximately 5 miles southeast of the watershed. The nearest daily monitoring stations are Woodstock (449263) and Edinburg (442663), which are approximately 13 miles and 7 miles north of the watershed, respectively.

Daily minimum and maximum temperature between 1980 and 2002 were used to compute the potential evapotranspiration time-series. This process is described in greater detail in Section 4.1.2.

Of the three precipitation stations, the Edinburg station was the most representative of the watershed; however, the data collected at this station are daily and the period of record started in 1996. The Woodstock station was used for the period from 1980 to 1996 and the normal-ratio method (Dunn and Leopold 1978) was used to disaggregate the daily rainfall data to hourly values based on hourly rainfall distributions at two other stations. First, a composite hourly distribution was determined as a weighted average hourly time-series of the two nearby stations. Second, the daily values were distributed to the resulting hourly time-series, keeping the original rainfall volume intact. Also using the same methodology, missing or deleted intervals in the data were simultaneously patched using the normal-weighted hourly distributions at the two nearby stations. This entire process is described in greater detail in Section 4.1.3.

4.1.2 Computing Potential Evapotranspiration

Daily minimum and maximum temperature data between 1980 and 2002 from the Edinburg and Woodstock 2 NE stations were used to compute the potential evapotranspiration time-series. The Hamon method (1961) was used to compute evapotranspiration. The Hamon formula states that:

$$PET = CTS \times DYL \times DYL \times VDSAT \quad \text{Eqn 5.1}$$

where

<i>PET</i>	daily potential evapotranspiration (in)
<i>CTS</i>	monthly variable coefficient (a value of 0.0055 is suggested)
<i>DYL</i>	possible hours of sunshine, in units of 12 hours, computed as a function of latitude and time of year
<i>VDSAT</i>	saturated water vapor density (absolute humidity) at the daily mean air temperature (g/cm ³)

The formula to compute saturated water vapor density (*VDSAT*) states that:

$$VDSAT = \frac{216.7 \times VPSAT}{TAVC + 273.3} \quad \text{Eqn 5.2}$$

where

<i>VPSAT</i>	saturated vapor pressure at the air temperature
<i>TAVC</i>	mean daily temperature computed from daily min and max (Deg C)

The formula for saturation vapor pressure (*VPSAT*) states that:

$$VPSAT = 6.108 \times \exp\left(\frac{17.26939 \times TAVC}{TAVC + 273.3}\right) \quad \text{Eqn 5.3}$$

Finally, the daily *PET* values were disaggregated to hourly time-series values using a standard sine wave equation, over the daylight hours (*DYL*), which reaches its peak at noon of each day.

4.1.3 Patching and Disaggregating Rainfall Data

Unless the percent coverage is 100%, meaning that the weather station is always in operation and is accurately recording data throughout the specified time period, precipitation stations may contain various intervals of accumulated, missing, or deleted data. Missing or deleted intervals are periods over which either the rainfall station malfunctioned or the data records were somehow lost. Accumulated intervals represent cumulative precipitation over several hours, but the exact hourly distribution of the data is unknown.

To disaggregate the daily rainfall totals to hourly values, each day that rainfall is recorded is treated as an accumulated interval over the 24-hour period. The normal-ratio method (Dunn & Leopold 1978) was used to repair accumulated, missing, and deleted data intervals based on hourly rainfall patterns at nearby stations where unimpaired data is measured. The normal-ratio method estimates a missing rainfall value using a weighted average from surrounding stations with similar rainfall patterns according to the relationship:

$$P_A = \frac{1}{n} \left(\sum_{i=1}^n \frac{N_A}{N_i} P_i \right) \quad \text{Eqn 5.4}$$

where P_A is the impaired precipitation value at station A , n is the number of surrounding stations with unimpaired data at the same specific point in time, N_A is the long term average precipitation at station A , N_i is the long term average precipitation at nearby station i , and P_i is the observed precipitation at nearby station i . For each impaired data record at station A , n consists of only the surrounding stations with unimpaired data; therefore, for each record, n varies from 1 to the maximum number of surrounding stations (two in this case). When no precipitation is available at the surrounding stations, zero precipitation is assumed at station A . The US Weather Bureau has a long established practice of using the long-term average rainfall as the precipitation normal. Since the normal ratio considers the long-term average rainfall as the weighting factor, this method is adaptable to regions where there is large orthographic variation in precipitation; therefore, elevation differences will not bias the predictive capability of the method. Figure 4.1 shows the 20-water-year annual rainfall totals at the Edinburg and Woodstock 2 NE stations by water year.

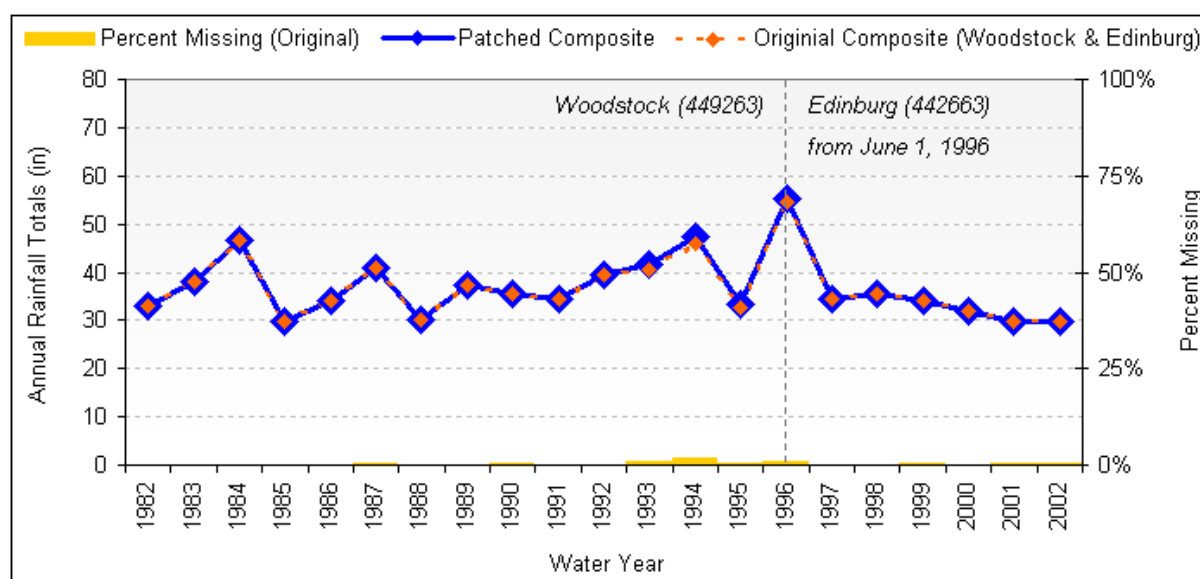


Figure 4.1 Total annual precipitation totals and daily quality at Woodstock and Edinburg gages before and after patching

4.2 Model Setup

LSPC was configured for the Smith Creek watershed to simulate the watershed as a series of hydrologically connected subwatersheds. Configuration of the model involved subdivision of the Smith Creek watershed into modeling units and continuous simulation of flow and water quality for these units using meteorological, land use, point source loading, and stream data. The watershed was subdivided into twenty subwatersheds to adequately represent the spatial variation in bacteria sources, watershed characteristics, hydrology, and the location of water quality monitoring and streamflow gaging stations. The delineation of subwatersheds was based primarily on the location of streams and a topographic analysis of the watershed. Subwatersheds and primary streams are shown in Figure 4.2. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

A continuous simulation period of thirteen years (1990-2002) was used in the hydrologic simulation analysis. This is due to the fact that the period of record for observation data spanned that time period. An important factor driving model simulations is precipitation data. The pattern and intensity of rainfall affects the build-up and wash-off of fecal coliform bacteria from the land into the streams, as well as the dilution potential of the stream.

Modeled land uses that contribute bacteria loads to the stream include pasture, cropland, urban land (including loads from failing septic systems and pets), and forest. Other sources, such as straight pipes and livestock in streams, were modeled as direct sources in the model. Development of initial loading rates for land uses and direct sources are described in Section 4.3.

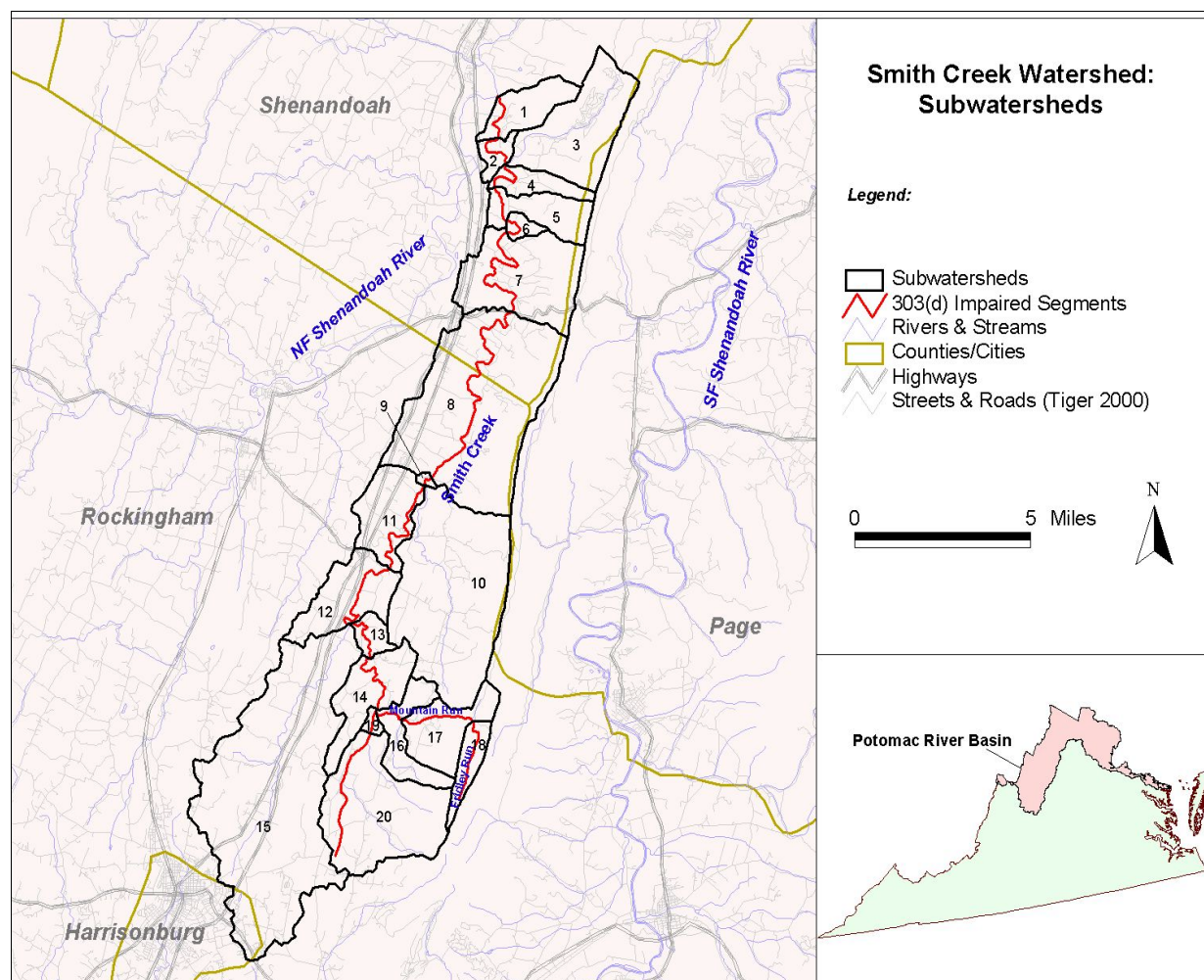


Figure 4.2 Smith Creek subwatersheds

4.3 Source Representation

Both point and nonpoint sources were represented in the model for Smith Creek. In general, point sources were added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources were represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (e.g. animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream.

4.3.1 Failing Septic Systems and Straight Pipes

Septic systems provide the potential to deliver bacteria loads to surface waters due to system failures caused by improper maintenance and/or malfunctions. The number of septic systems in each subwatershed was determined using U.S. Census Year 2000 block-group data for Shenandoah and Rockingham Counties, as described in Section 3.1.1 (Table 4.3). The percentage of urban land in each subwatershed was used to determine the septic population in each subwatershed. The number of failing septic systems was estimated using a failure rate of 4% based on information provided by the Virginia Department of Health (Kelly Vanover, VDH, pers. comm. 2004). Failing septic discharges contribute bacteria to the stream through runoff events (included in the urban land load).

In some cases, human waste is directly deposited into surface waters from houses without septic systems. The population served by straight pipes was assumed to be 0.5% of the septic population in the watershed (Kelly Vanover, VDH, pers. comm. 2004). These direct discharges are a constant source of bacteria to the receiving stream. Houses considered to have a normal functioning septic system were assumed to have a negligible contribution of fecal bacteria to surface waters.

Table 4.3 Total and failing septic population estimates (by subwatershed)

Subwatershed	Septic Population	Population served by failing septic systems
1	288	12
2	4	0
3	364	15
4	0	0
5	0	0
6	3	0
7	1,049	42
8	1,873	75
9	0	0
10	605	24
11	270	11
12	299	12
13	112	4
14	113	5
15	1,520	61
16	158	6

Subwatershed	Septic Population	Population served by failing septic systems
17	158	6
18	0	0
19	0	0
20	411	16

* 36 people estimated to be using straight pipes

4.3.2 Livestock

Bacteria produced by livestock can be deposited on the land, directly deposited in the stream (as is common when grazing animals have stream access), manually applied to cropland and other agricultural lands as fertilizer, or contributed to surface waters through illicit discharges from animal confinement areas. Bacteria deposited on the land, either directly or through manure application, are available for washoff into surface waters during rainfall events. There are no known illicit discharges of animal waste in the watershed.

Animal population estimates for dairy cattle and poultry (chickens and turkeys) were based on combined animal feeding operation (CAFO) data for the Smith Creek watershed provided by VADCR. Livestock population data for horses, hogs/pigs, and sheep/lambs were obtained from the 1997 Virginia Agricultural Census data for Shenandoah and Rockingham Counties (VASS 1997). Bacteria loads directed through each pathway were calculated by multiplying the bacteria density with the amount of waste expected through that pathway.

The population of each livestock species was distributed among subwatersheds based on the total area of pasture in each subwatershed (Table 4.4).

Table 4.4 Livestock population by subwatershed

Subwatershed	Beef Cattle	Dairy Cattle	Hogs	Sheep	Chickens (& Broilers)	Horses
1	78	0	9	20	0	3
2	50	0	6	13	0	2
3	23	0	30	65	0	1
4	62	0	8	18	0	3
5	73	0	10	21	25,000	3
6	20	0	3	6	0	1
7	223	75	30	65	138,800	9

Subwatershed	Beef Cattle	Dairy Cattle	Hogs	Sheep	Chickens (& Broilers)	Horses
8	595	75	81	173	196,000	24
9	12	0	2	3	0	0
10	470	495	83	125	139,000	25
11	229	60	41	32	48,000	12
12	261	0	24	36	102,000	14
13	56	0	6	10	30,000	3
14	177	0	21	31	15,000	9
15	1,170	340	138	207	174,000	62
16	61	0	28	42	0	3
17	32	0	15	22	14,500	2
18	0	0	0	0	0	0
19	17	0	3	4	0	1
20	314	430	52	79	81,000	17

Liquid manure from confined animals is applied to cropland and pasture/hayland in the Smith Creek watershed. Application rates vary monthly, with application primarily occurring during the spring and fall, according to the schedule presented in Section 3.1.2. Application of manure results in the accumulation of bacteria on the land surface. Therefore, bacteria accumulation rates are directly influenced by and based on the application rates of manure. To determine bacteria accumulation factors for the model, it was necessary to determine the amount present in manure. The fraction of manure application available for runoff was calculated by subtracting the amount typically incorporated into the soil matrix through tillage and natural processes (assumed 25% soil incorporation).

Beef and dairy cattle in streams were represented in the model as direct inputs (e.g. point sources) of bacteria. Using the fecal coliform bacteria production rates for beef and dairy cattle, the daily contribution from cattle in streams was calculated and then totaled by subwatershed depending on the population estimates of beef and dairy cattle watering in streams in each subwatershed (refer to Section 3.1.2). Bacteria contributions from cattle in streams were represented in the model using the total load delivered to the stream (#/day) and the flow rate at which it is delivered (cfs). The flow rate was determined using the amount of waste produced by beef and dairy cattle each day (lb/day) and an assumed density of the manure produced (lb/gal). Cattle in the stream were assumed to discharge at a constant rate.

Grazing animals also contribute bacteria to the land surface, which is available for washoff to surface waters during storm events. Beef and dairy cattle were the most abundant grazing animals in the watershed, as shown in Table 4.4. Sheep and horses represent the only other significant grazing livestock species in the Smith Creek watershed. Cattle, sheep, and horses were distributed throughout pasture/hay areas in each subwatershed. Bacteria accumulation rates (#/acre/day) for each of these livestock species were calculated using subwatershed population estimates and the bacteria production rate established for each species.

4.3.3 Wildlife

The population of each wildlife species was estimated using the population density per square mile of habitat and the total area of suitable habitat in each subwatershed (Table 4.5). As with grazing livestock, wildlife deposit manure on the land and directly to surface waters. The habitat and percentage of time each species typically spends in streams was used to determine the proportion of bacteria that was deposited on land versus directly to surface waters. Loads applied to the land (in each subwatershed) were distributed according to the total area of each land use type within the established habitat area of each species.

Table 4.5 Wildlife population by subwatershed

Subwatershed	Ducks		Geese		Deer	Beaver	Raccoon	Muskrat
	Summer	Winter	Summer	Winter				
1	4	6	6	9	77	0.3	4	6
2	4	6	6	8	22	0.3	2	6
3	10	17	5	7	229	1.5	24	26
4	5	7	7	10	54	0.3	4	6
5	8	11	12	17	91	0.4	6	10
6	3	4	4	5	18	0.2	2	4
7	24	35	33	47	231	1.6	19	36
8	31	44	47	66	559	1.9	25	42
9	1	2	2	3	5	0.1	0	2
10	32	46	45	63	469	2.1	30	49
11	8	13	10	14	113	0.7	6	14
12	8	11	11	15	129	0.5	7	11
13	4	6	6	9	30	0.3	3	6
14	7	10	10	15	125	0.4	6	9
15	13	17	20	28	710	0.5	10	16

Subwatershed	Ducks		Geese		Deer	Beaver	Raccoon	Muskrat
	Summer	Winter	Summer	Winter				
16	2	3	3	4	84	0.2	3	4
17	5	8	4	5	116	0.6	10	10
18	2	3	0	0	49	0.3	5	5
19	2	3	3	4	10	0.1	1	3
20	1	1	1	1	306	0.1	2	1

4.3.4 Domestic Pets

Housing estimates were used to determine the number of pets in each Smith Creek subwatershed (Census 2000). An assumption of one dog per household was used to calculate the pet population. Bacteria loading was applied to urban (built-up) lands and as direct deposition to the stream in each subwatershed.

4.4 Stream Characteristics

The channel geometry for the stream reaches in Smith Creek subwatersheds were based on the visual observation of stream channel configurations throughout the watershed and through an analysis of typical stream channel geometry values for these stream types. The stream segment length and slope values for each subwatershed were determined using GIS analysis of digitized streams and digital elevation models (DEMs).

4.5 Selection of a Representative Modeling Period

The selection of a representative modeling period was based on the availability of stream flow and water quality data collected in the Smith Creek watershed that cover varying wet and dry time periods. Hourly flow discharge data were available from the USGS gage located in the lower portion of the watershed (USGS 01632900) from 1980 through 2002. Monthly water quality data were also collected by VADEQ on Smith Creek during this period; therefore, this time period was selected for modeling purposes. This time period represented varying climatic and hydrologic conditions, including dry, average, and wet periods that typically occur in the area. This was an important consideration because during dry weather and low flow periods, constant direct discharges primarily affect instream concentrations; however, during wet weather and high flow periods, surface runoff delivers nonpoint source bacteria loads to the stream, affecting instream concentrations more so than direct discharges.

4.6 Model Calibration Process

Hydrology and water quality calibration were performed in sequence, since water quality modeling is dependent on an accurate hydrology simulation. Hydrology was the first model component calibrated. The hydrology calibration involved a comparison of model results to stream flow observations at the USGS gage on Smith Creek (01632900 - Smith Creek near New Market, VA).

The model was calibrated using daily stream flow data from USGS gage 01632900 for two selected during the 1990s. Model calibration years were selected using the following four criteria:

1. Completeness of the weather data available for the selected period.
2. Representation of low-flow, average-flow, and high-flow water years.
3. Consistency of selected period with key model inputs (i.e. land use coverage)
4. Quality of initial modeled versus observed data correlation

Based on a review of these four selection criteria, two calibration periods 1990 to 1991, and 1996 to 1997 were chosen as model calibration years. The MRLC land use coverage used in the model was developed during the mid 1990s, therefore, the selected calibration periods are consistent with this key model input. The model was validated for long-term and seasonal representation of hydrologic trends using a 13-year period (1990-2002).

Model calibration was performed using the error statistics criteria specified in HSPEXP, temporal comparisons, and comparisons of seasonal, high flows, and low flows. Calibration involved the adjustment of infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters. After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data. Hydrology calibration and validation results are shown in Figures 4.3 through 4.10 and Tables 4.6 through 4.9.

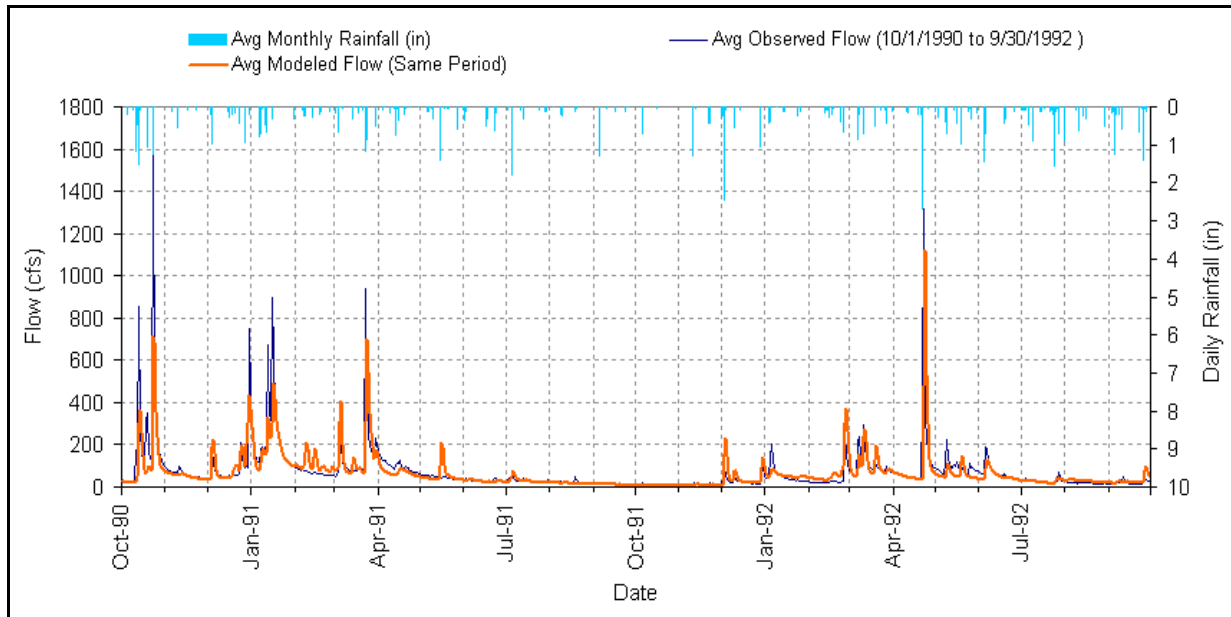


Figure 4.3 Daily flow calibration comparison for water years 1990-1991 at USGS 01632900

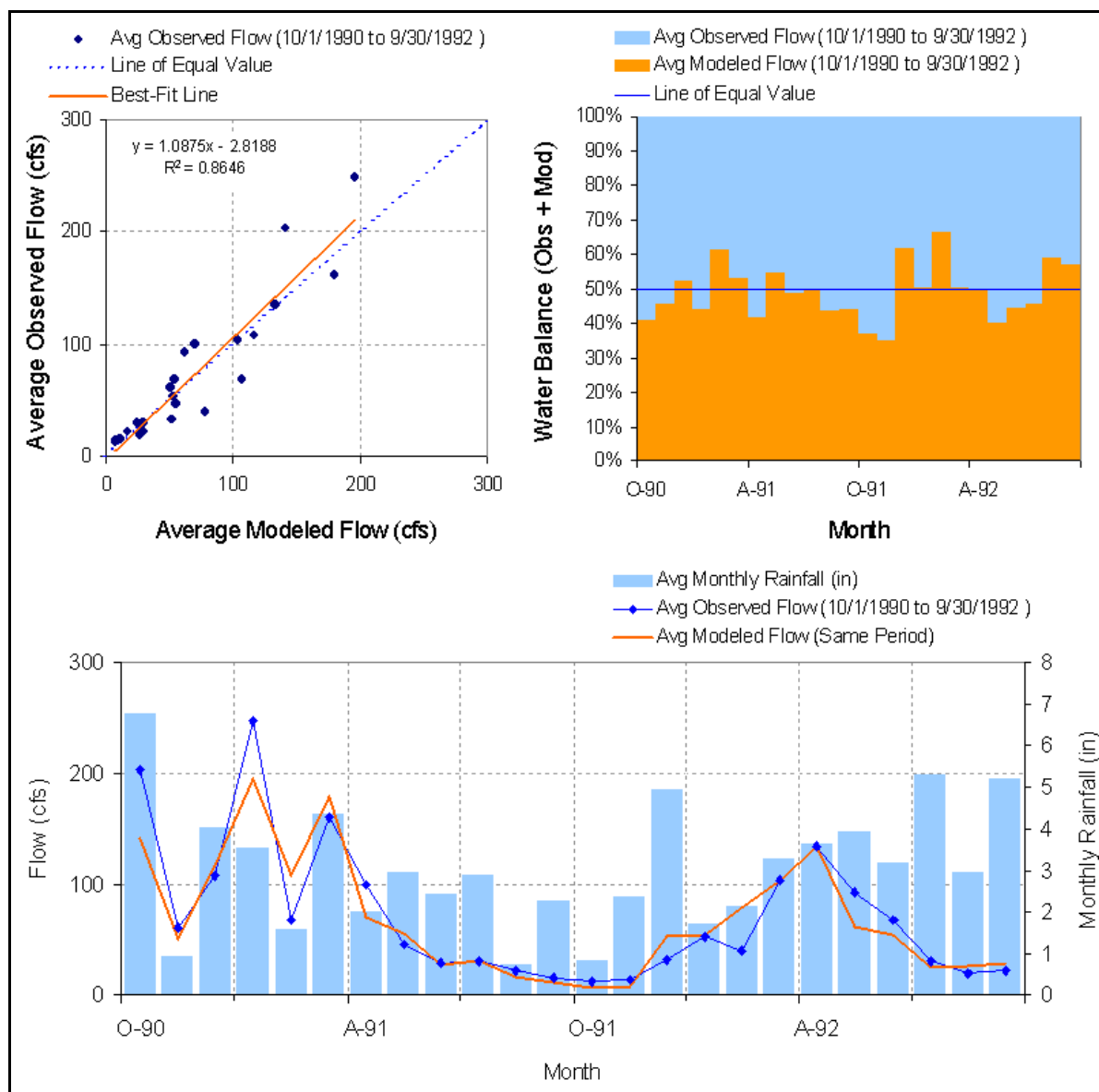
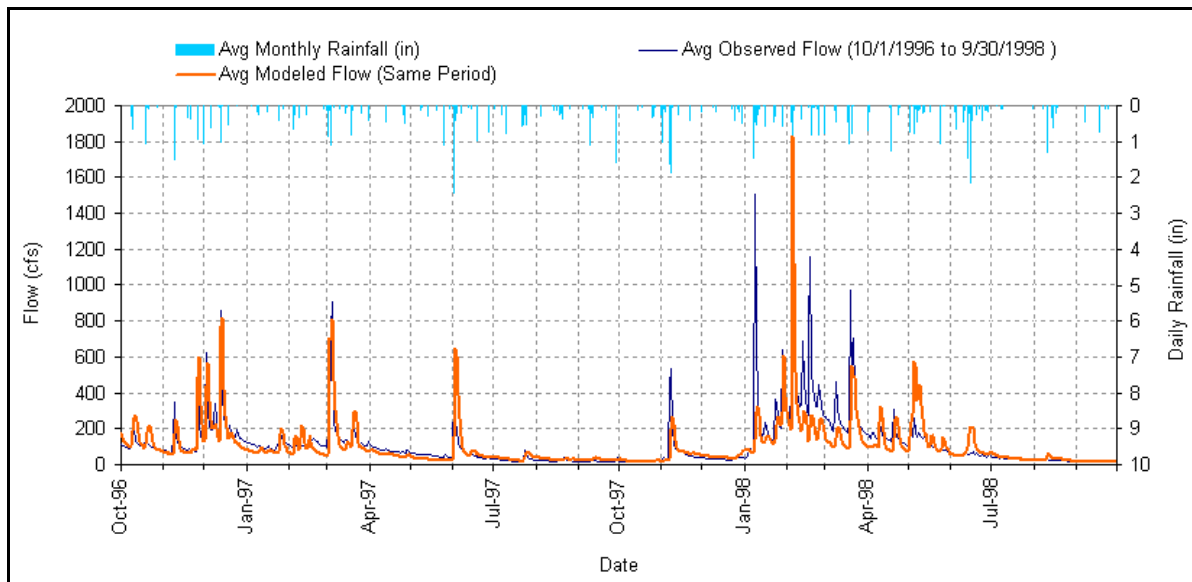


Figure 4.4 Monthly flow calibration comparison for water years 1990-1991 at USGS 01693200

Table 4.6 Error statistics for calibration water years 1990-1991

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 5		USGS 01632900 SMITH CREEK NEAR NEW MARKET, VA	
2-Year Analysis Period: 10/1/1990 - 9/30/1992 Flow volumes are (inches/year) for upstream drainage area		Shenandoah County, Virginia Hydrologic Unit Code 02070006 Latitude 38°41'36", Longitude 78°38'35" NAD27 Drainage area 93.20 square miles	
Total Simulated In-stream Flow:	9.96	Total Observed In-stream Flow:	10.45
Total of simulated highest 10% flows:	4.18	Total of Observed highest 10% flows:	4.49
Total of Simulated lowest 50% flows:	1.64	Total of Observed Lowest 50% flows:	1.65
Simulated Summer Flow Volume (months 7-9):	0.86	Observed Summer Flow Volume (7-9):	0.85
Simulated Fall Flow Volume (months 10-12):	2.31	Observed Fall Flow Volume (10-12):	2.66
Simulated Winter Flow Volume (months 1-3):	4.35	Observed Winter Flow Volume (1-3):	4.11
Simulated Spring Flow Volume (months 4-6):	2.44	Observed Spring Flow Volume (4-6):	2.85
Total Simulated Storm Volume:	3.79	Total Observed Storm Volume:	3.59
Simulated Summer Storm Volume (7-9):	0.14	Observed Summer Storm Volume (7-9):	0.14
<i>Errors (Simulated-Observed)</i>	<i>Error Statistics</i>	<i>Recommended Criteria</i>	
Error in total volume:	-4.98	10	
Error in 50% lowest flows:	-0.41	10	
Error in 10% highest flows:	-7.46	15	
Seasonal volume error - Summer:	1.12	30	
Seasonal volume error - Fall:	-14.91	30	
Seasonal volume error - Winter:	5.64	30	
Seasonal volume error - Spring:	-16.64	30	
Error in storm volumes:	5.42	20	
Error in summer storm volumes:	1.61	50	


Figure 4.5 Daily flow calibration comparison for water years 1996-1997 at USGS 01632900

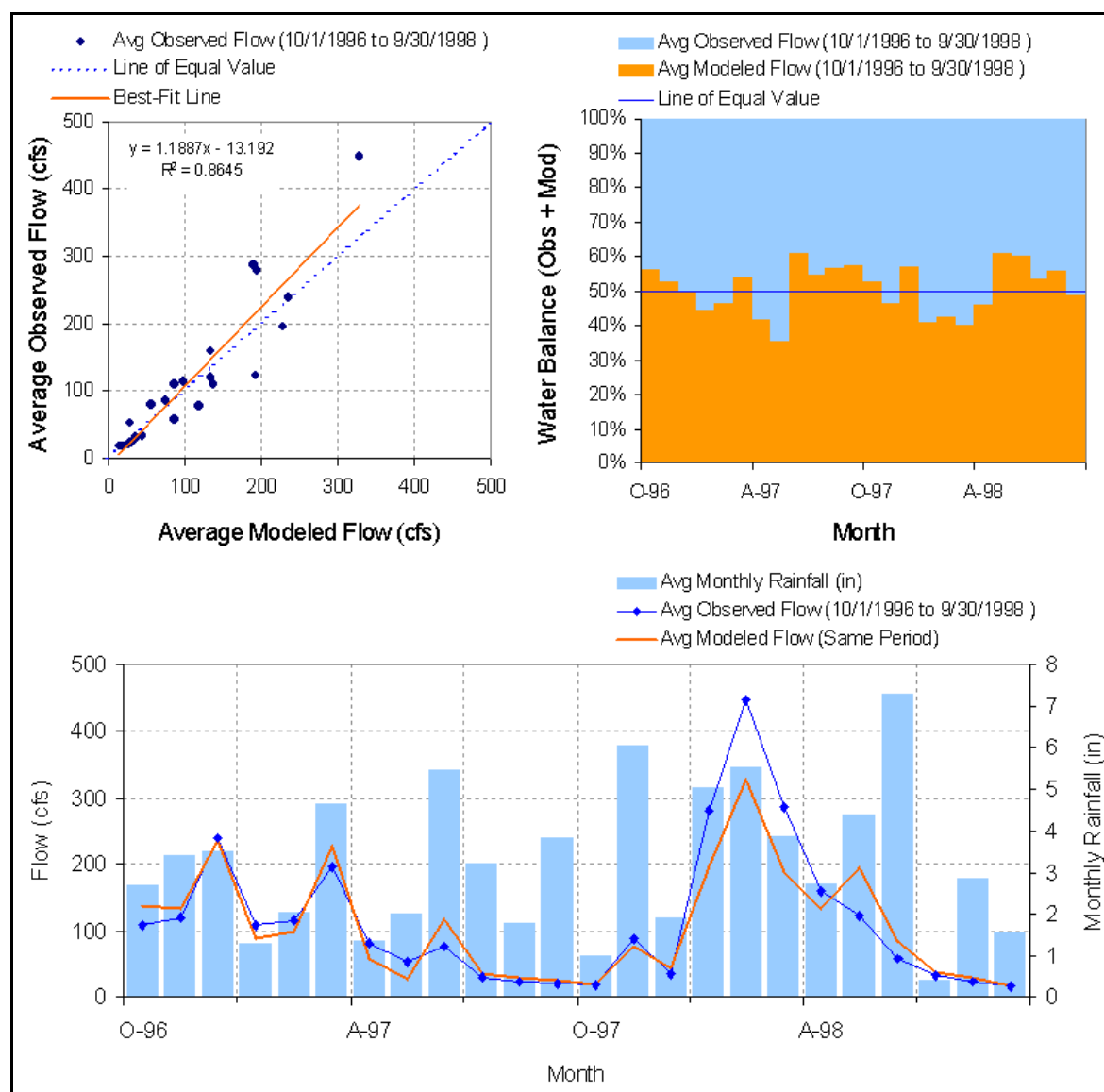


Figure 4.6 Monthly flow calibration comparison for water years 1996-1997 at USGS 01693200

Table 4.7 Error statistics for calibration water years 1996-1997

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 5 2-Year Analysis Period: 10/1/1996 - 9/30/1998 Flow volumes are (inches/year) for upstream drainage area		USGS 01632900 SMITH CREEK NEAR NEW MARKET, VA Shenandoah County, Virginia Hydrologic Unit Code 02070006 Latitude 38°41'36", Longitude 78°38'35" NAD27 Drainage area 93.20 square miles	
Total Simulated In-stream Flow:	15.47	Total Observed In-stream Flow:	16.43
Total of simulated highest 10% flows:	6.11	Total of Observed highest 10% flows:	6.50
Total of Simulated lowest 50% flows:	2.53	Total of Observed Lowest 50% flows:	2.44
Simulated Summer Flow Volume (months 7-9):	1.06	Observed Summer Flow Volume (7-9):	0.88
Simulated Fall Flow Volume (months 10-12):	3.96	Observed Fall Flow Volume (10-12):	3.71
Simulated Winter Flow Volume (months 1-3):	6.72	Observed Winter Flow Volume (1-3):	8.53
Simulated Spring Flow Volume (months 4-6):	3.74	Observed Spring Flow Volume (4-6):	3.31
Total Simulated Storm Volume:	5.94	Total Observed Storm Volume:	4.61
Simulated Summer Storm Volume (7-9):	0.14	Observed Summer Storm Volume (7-9):	0.10
<i>Errors (Simulated-Observed)</i>	<i>Error Statistics</i>	<i>Recommended Criteria</i>	
Error in total volume:	-6.19	10	
Error in 50% lowest flows:	3.41	10	
Error in 10% highest flows:	-6.40	15	
Seasonal volume error - Summer:	16.87	30	
Seasonal volume error - Fall:	6.27	30	
Seasonal volume error - Winter:	-26.94	30	
Seasonal volume error - Spring:	11.35	30	
Error in storm volumes:	22.34	20	
Error in summer storm volumes:	26.96	50	

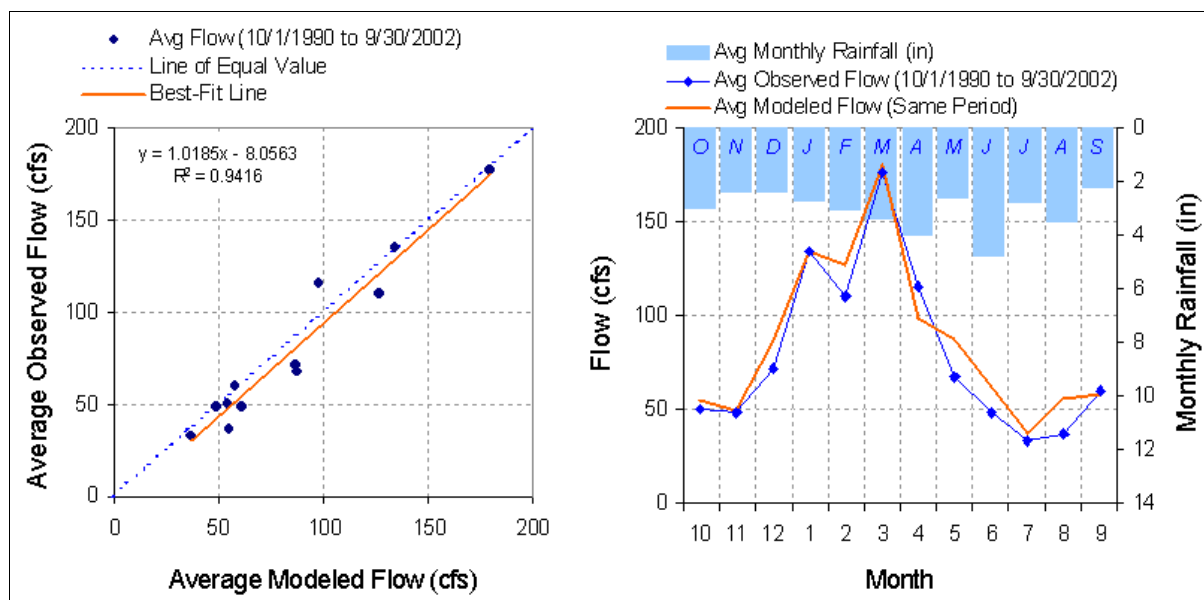


Figure 4.7 13-year annualized composite validation at USGS01632900 (Water Years 1990-2002)

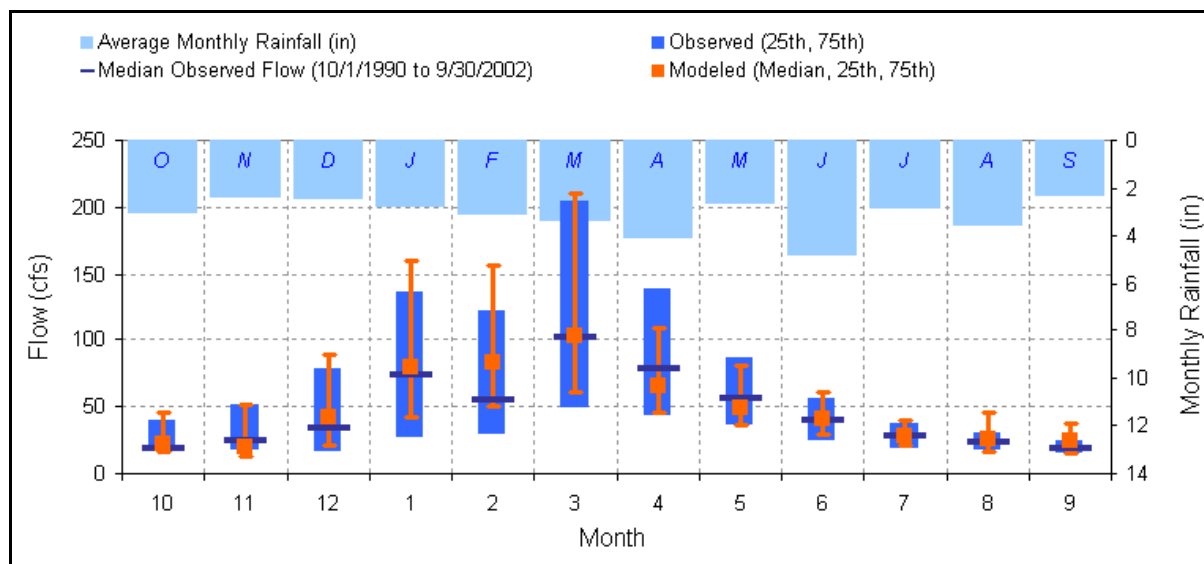


Figure 4.8 13-year annualized composite validation at USGS 01632900 for seasonal trend analysis (Water Years 1990-2002)

Table 4.8 Table of summary statistics for 13-year annualized validation at USGS 01632900

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	49.82	19.00	16.00	39.25	54.15	22.12	16.08	45.86
Nov	48.32	25.00	17.00	51.00	48.69	20.19	12.86	51.64
Dec	71.28	34.00	16.00	78.00	86.51	42.51	20.93	88.97
Jan	134.25	74.00	27.00	137.00	134.20	79.75	41.61	159.64
Feb	109.94	55.00	29.00	121.00	127.16	83.25	49.79	156.72
Mar	176.26	102.00	49.00	204.25	179.25	102.92	60.41	210.79
Apr	115.11	78.00	43.00	139.25	98.03	65.79	45.12	108.71
May	67.39	56.00	35.75	87.00	87.72	49.42	36.17	80.38
Jun	48.22	40.00	25.00	56.25	61.24	41.33	29.78	61.33
Jul	32.67	28.00	19.00	37.00	37.24	28.19	20.67	39.65
Aug	36.60	23.00	18.00	30.00	55.05	25.67	15.86	45.98
Sep	60.04	19.00	15.00	25.00	58.34	24.59	15.08	36.93

Table 4.9 Error statistics for validation period (Water Years 1990 to 2002)

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 5		USGS 01632900 SMITH CREEK NEAR NEW MARKET, VA	
12-Year Analysis Period: 10/1/1990 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		Shenandoah County, Virginia Hydrologic Unit Code 02070006 Latitude 38°41'36", Longitude 78°38'35" NAD27 Drainage area 93.20 square miles	
Total Simulated In-stream Flow:	12.47	Total Observed In-stream Flow:	11.52
Total of simulated highest 10% flows:	5.83	Total of Observed highest 10% flows:	5.55
Total of Simulated lowest 50% flows:	1.72	Total of Observed Lowest 50% flows:	1.50
Simulated Summer Flow Volume (months 7-9):	1.84	Observed Summer Flow Volume (7-9):	1.58
Simulated Fall Flow Volume (months 10-12):	2.32	Observed Fall Flow Volume (10-12):	2.08
Simulated Winter Flow Volume (months 1-3):	5.31	Observed Winter Flow Volume (1-3):	5.08
Simulated Spring Flow Volume (months 4-6):	2.99	Observed Spring Flow Volume (4-6):	2.79
Total Simulated Storm Volume:	4.97	Total Observed Storm Volume:	4.10
Simulated Summer Storm Volume (7-9):	0.69	Observed Summer Storm Volume (7-9):	0.63
<i>Errors (Simulated-Observed)</i>	<i>Error Statistics</i>	<i>Recommended Criteria</i>	
Error in total volume:	7.57	10	
Error in 50% lowest flows:	12.80	10	
Error in 10% highest flows:	4.74	15	
Seasonal volume error - Summer:	14.36	30	
Seasonal volume error - Fall:	10.61	30	
Seasonal volume error - Winter:	4.34	30	
Seasonal volume error - Spring:	6.78	30	
Error in storm volumes:	17.54	20	
Error in summer storm volumes:	8.18	50	

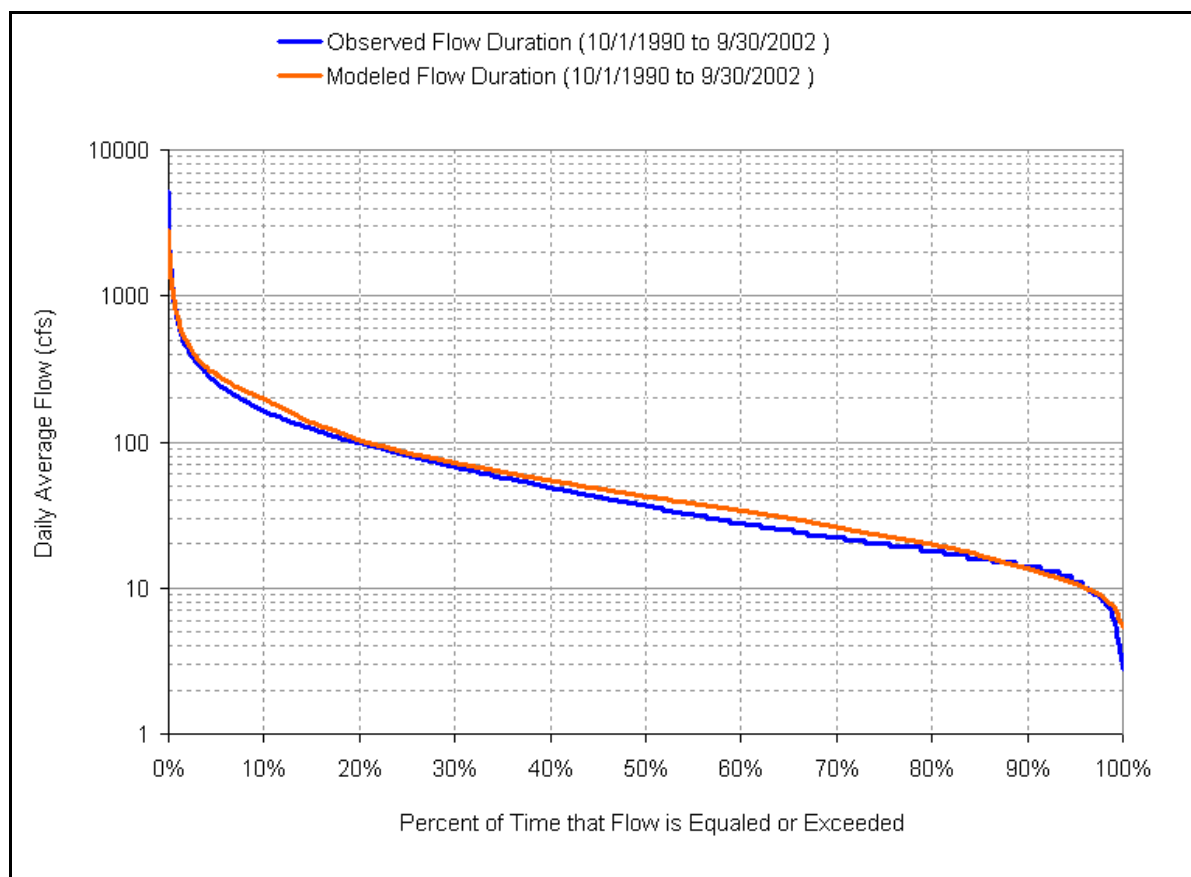


Figure 4.9 Model versus observed flow duration-exceedance curves for 1990 to 2002 at USGS01632900

It is important to note that although the semi-log plot allows for comparative visualization of flows that span several orders of magnitude, this type of graph tends to diminish the differences in high flows, while exaggerating the differences in low flows. The validity of any hydrology calibration must be evaluated using multiple comparisons like those shown previously.

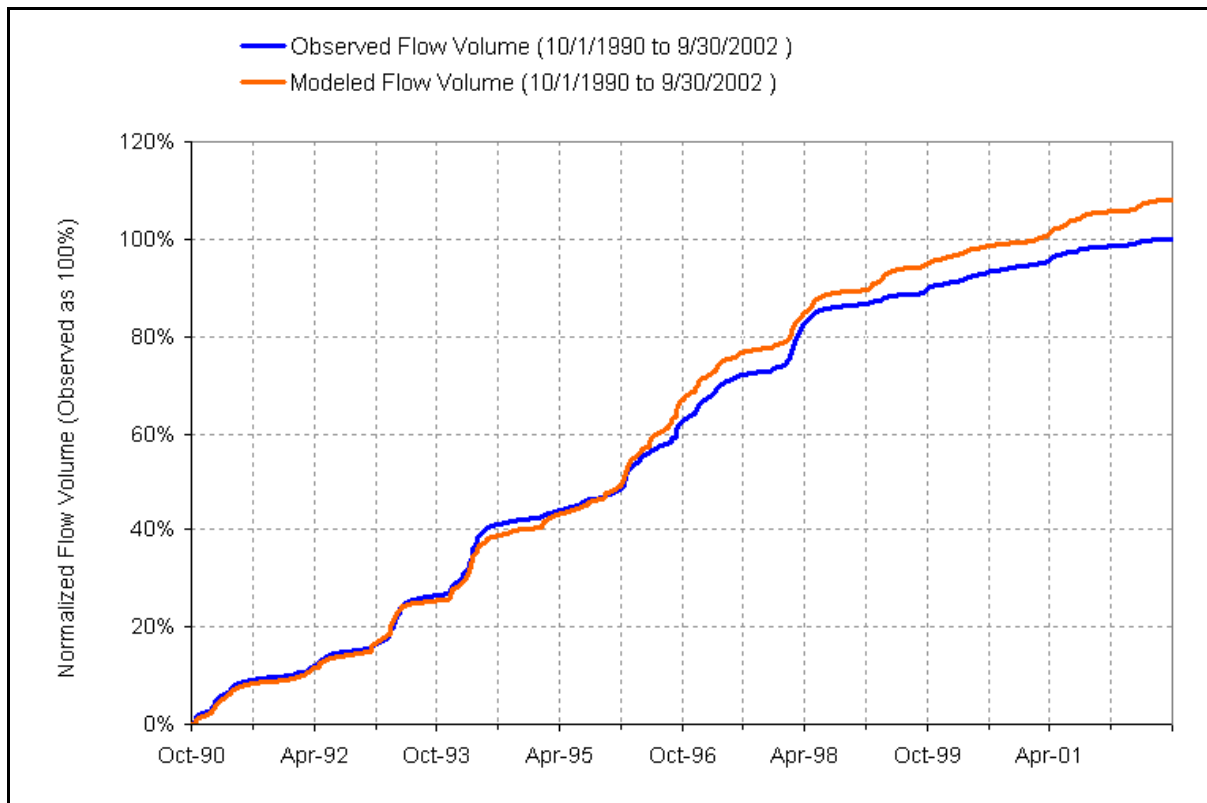


Figure 4.10 Modeled versus observed cumulative flow curves for 1990 to 2002 at USGS01632900

Fecal coliform accumulation and surface loading parameters for land uses were calculated based on contributions from various sources, as discussed in Section 3. After incorporating these model parameters and inputs, as well as contributions from livestock and wildlife point sources, failing septic systems, and background concentrations in the streams, modeled in-stream fecal coliform bacteria concentrations were compared to observed data. The modeled concentrations closely correspond to the observed fecal coliform values, as shown in Figures 4.11 and 4.12. The relative pattern of observed concentration levels is maintained in the modeled concentrations. It should be noted that the difference between the highest fecal coliform observed values and the modeled peak concentrations is due to laboratory detection limits which cap the maximum reported concentration at 8,000 cfu/100mL. Because of these maximum laboratory detection limits, the actual value may be significantly higher than the reported detection limit.

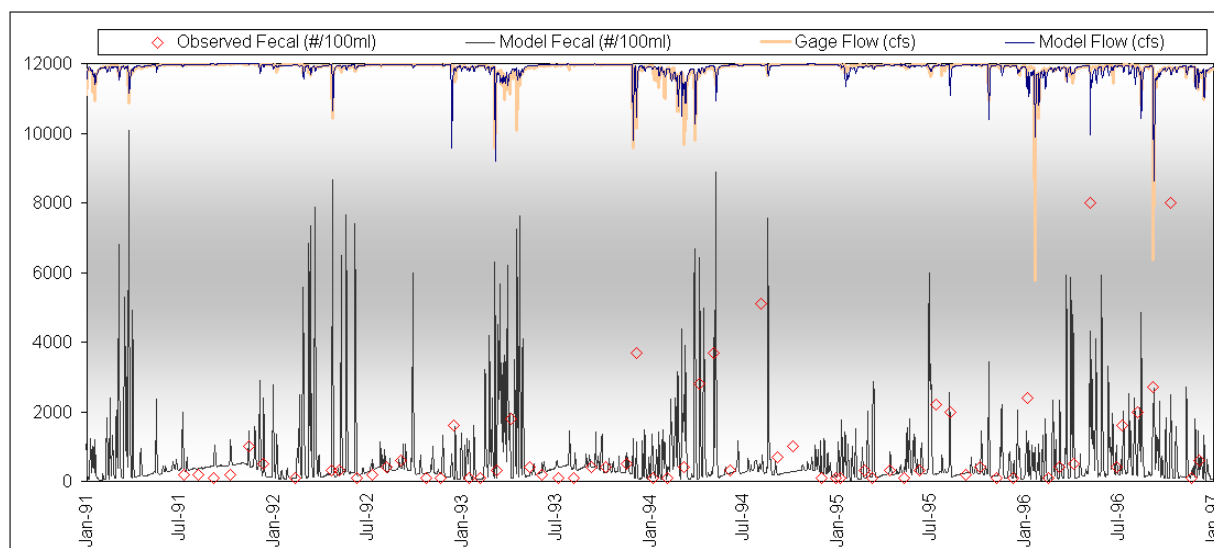


Figure 4.11 Water quality calibration at 1BSMT004.60 on Smith Creek 1991 to 1996

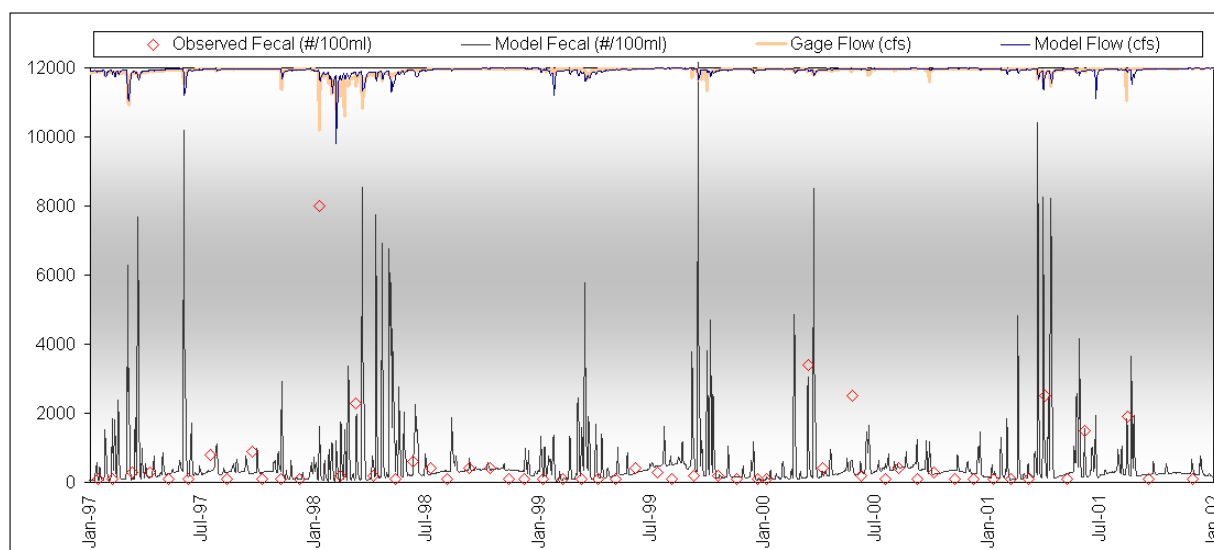


Figure 4.12 Water quality validation at 1BSMT004.60 on Smith Creek 1997 to 2002

4.7 Existing Loadings

The model was run for the representative hydrologic period January 1, 1990 through December 31, 2002. The modeling run represents the existing bacteria concentrations and loadings at the watershed outlet. Figure 4.13 shows the existing instantaneous and geometric mean concentrations of *E. coli* for Smith Creek, using the VADEQ fecal coliform bacteria/*E. coli* translator (VADEQ 2003). These data were compared to the 235 cfu/100mL instantaneous and 126 cfu/100mL geometric mean water quality criteria for *E. coli* to assess the magnitude of in-stream concentrations. Existing *E. coli* loadings by land use category for Smith Creek are presented in Sections 8. These values represent the contribution of *E. coli* loads from all sources in the watershed.

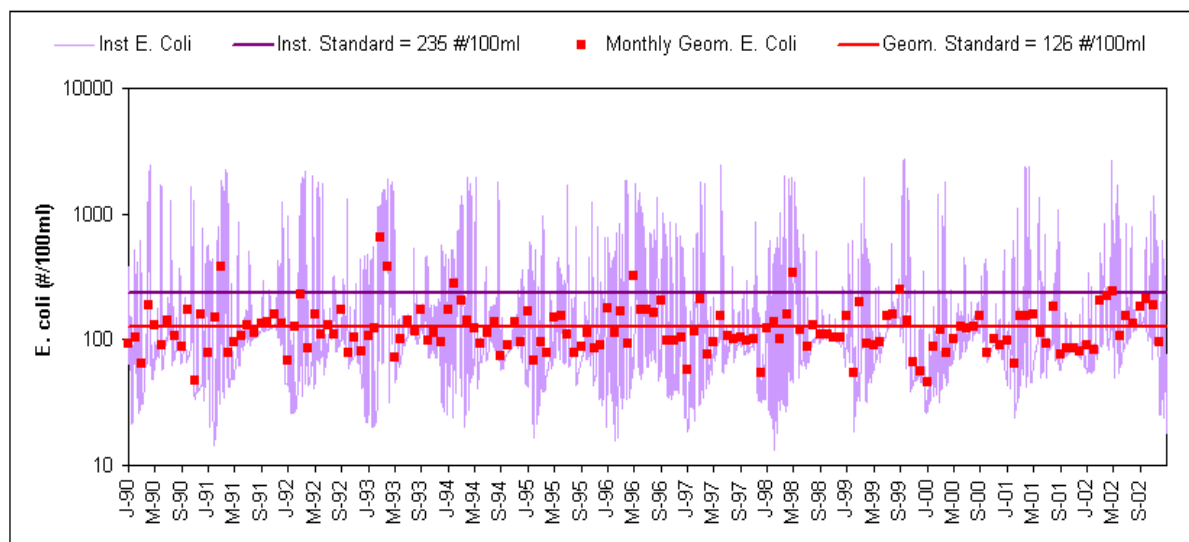


Figure 4.13 Instantaneous and geometric mean concentrations of *E. coli* from 1990 to 2002

SECTION 5

BENTHIC STRESSOR IDENTIFICATION

5.1 Stressor Identification Process

Biological assessments are useful in detecting impairment, but they do not necessarily identify the cause(s) of impairment. EPA developed the *Stressor Identification: Technical Guidance Document* to assist water resource managers in identifying stressors or combinations of stressors that cause biological impairment (Cormier et al. 2000). Elements of the stressor identification process were used to evaluate and identify the primary stressors of the benthic community in Smith Creek, Mountain Run, and Fridley Run. Watershed and water quality data from these streams, reference watershed data, and field observations were used to help identify candidate causes.

5.2 Candidate Causes

Based on information provided by VADEQ and watershed data collected at the beginning of the TMDL study, it was hypothesized that excessive sedimentation was responsible for the listed benthic impairments. The high number of pollution-tolerant organisms (hydropsychids, chironomids, oligochaetes, etc.) indicate poor water quality and habitat conditions. A field visit to the Smith Creek watershed was conducted by Tetra Tech, GMU, and VADEQ personnel on April 25, 2003 to gather information on stream and watershed characteristics for stressor identification and modeling studies. Field observations confirmed the likelihood that sedimentation was primarily responsible for negative impacts to the benthic macroinvertebrate community in this stream and its tributaries. Additional sampling visits were conducted by GMU personnel during the TMDL study to further quantify water quality and biological conditions in the Smith Creek watershed. Potential stressors and their relationships to benthic community condition are discussed below.

5.2.1 Temperature

Temperature affects the metabolic rates of aquatic organisms, photosynthesis of aquatic plants, parasites, pathogens, and can influence the toxicity of some pollutants. In addition, higher water temperatures reduce the oxygen saturation capacity of the water, which can have negative effects on organisms that require a certain amount of dissolved oxygen to sustain life.

Humans can influence water temperature by direct thermal pollution, altering land cover and land use within a watershed, or removing vegetation within the riparian zone. Temperature can also be increased by increasing turbidity, which allows more solar radiation to be absorbed by the water.

5.2.2 pH

pH can negatively affect organisms when it is both too high and too low. As a result, an appropriate pH level for healthy stream ecosystems is often considered to be between 6.0 and 9.0 standard units. Low pH conditions (acidity) can be caused by various sources including runoff, acidic precipitation and deposition, and point source discharges. High pH is often associated with excess primary production of algae, which alters the balance of carbonates in the water. In Virginia streams, low pH is typically a more common problem than high pH.

pH levels outside the acceptable range can cause numerous secondary impacts as well. For example, when pH is low, aluminum ions can be mobilized and attach to the gills of freshwater organisms, resulting in decreased respiratory efficiency and, in some cases, mortality. In the case of high pH, the level of unionized ammonia in the water column increases resulting in potential toxic impacts to aquatic organisms. Reduced emergence and mortality of stoneflies, mayflies, and dragonflies at pH levels greater than 9.5 has also been noted in freshwater studies (NAS/NAE 1972).

5.2.3 Low Dissolved Oxygen

Organic enrichment can cause low dissolved oxygen (DO) levels which stress benthic organisms. In general, high nitrogen and phosphorus levels can lead to increased production of algae and macrophytes, which can result in the depletion of oxygen in the water column through metabolic respiration. In addition, at higher water temperatures the concentration of dissolved oxygen is lower because the solubility of oxygen (and other gases) decreases with increasing temperature. Higher water temperatures can be caused by the loss of shading, higher evaporation rates, reduced stream flow, and other factors.

Aquatic organisms, including benthic macroinvertebrates, are dependent upon an adequate concentration of dissolved oxygen. Less tolerant organisms generally cannot survive or are outcompeted by more tolerant organisms under low dissolved oxygen conditions. This process reduces diversity and alters community composition from a natural state. Aquatic insects and other benthic organisms serve as food items for fishes, therefore, alterations in the benthic community can impact fish feeding ecology (Hayward and Margraf 1987; Leach et al. 1977).

5.2.4 Organic Matter

Excess organic matter can directly interfere with the habitat of numerous benthic organisms. In excess amounts, particulate organic matter (POM) can clog the substrate, covering or filling acceptable benthic habitat. Dissolved organic matter (DOM) affects water clarity and nutrient availability. Furthermore, organic matter can alter the pH of water through decomposition and the release of excess nutrients into the aquatic environment can have further negative consequences.

5.2.5 Nutrients

Excess nutrient concentrations have been documented to have numerous secondary negative impacts on aquatic biota. In general, nutrient over-enrichment can lead to eutrophication or hypereutrophication of a waterbody. Under these conditions, algal blooms become more common, sedimentation increases, and there is a pronounced shift in trophic state. Negative consequences can include increased turbidity, a decreased photic zone, local extinction of specialized or intolerant aquatic flora, high pH levels, low dissolved oxygen, and decreased substrate stability.

Excess nutrients in streams are often caused by runoff from agriculture and livestock, direct or “straight pipe” additions, suburban lawns, acid rain, golf courses, and leaky or inefficient septic systems. Although the effects of excessive nutrient concentrations have been documented in various stream assessments, lakes and other larger waterbodies (e.g. Chesapeake Bay), are particularly susceptible to nutrient enrichment due to lower flushing rates and other factors.

5.2.6 Sedimentation

Excessive sedimentation from anthropogenic sources is a common problem that can impact the stream biota in a number of ways. Deposited sediments reduce habitat complexity by filling pools, critical riffle areas, and the interstitial spaces used by aquatic invertebrates. Substrate size is a particularly important factor that influences the abundance and distribution of aquatic insects. Sediment particles at high concentrations can directly affect aquatic invertebrates by clogging gill surfaces and lowering respiration capacity. Suspended sediment also increases turbidity in the water column which can affect the feeding efficiency of visual predators and filter feeders. In addition, pollutants, such as phosphorus, adsorb to sediment particles and are transported to streams through erosion processes.

Habitat Alteration and Riparian Vegetation

Sedimentation and habitat alteration are often directly related. The lack of an adequate riparian buffer along stream sections is often considered to be a potential factor affecting the benthic community. Minimal riparian vegetation was observed in specific areas during field visits. These riparian areas perform many functions that are critical to the ecology of the streams that they border. Functional values include: flood detention, bank stabilization, nutrient cycling, wildlife habitat, and canopy shading which decreases water temperature and increases baseflow through lower evaporation rates.

5.2.7 Toxic Pollutants

Toxic pollutants in the water column and sediment can result in acute and chronic effects on aquatic organisms. Increased mortality rates, reduced growth and fecundity, respiratory problems, tumors,

deformities, and other consequences have been documented in toxicity studies of aquatic organisms. Degraded water quality conditions and other environmental stressors can lead to higher rates of incidence of these problems. Most often, toxic pollutants found in high concentrations in freshwater are there due to anthropogenic activities.

5.3 Monitoring Stations

There are thirteen current and historical VADEQ water quality monitoring stations located in the Smith Creek watershed. Biomonitoring data were collected at VADEQ stations 1BSMT005.71 and 1BSMT006.62 on Smith Creek, VADEQ station 1BLAC000.14 on Lacey Spring Branch, and several USFS stations on Mountain Run and Fridley Run. As part of the benthic TMDL study, GMU personnel conducted water quality and biomonitoring at thirteen stations on Smith Creek, Mountain Run, and Fridley Run. Several of the GMU stations are co-located with VADEQ monitoring stations. VADEQ, GMU, and USFS stations in the Smith Creek watershed are presented in Table 2.2 and Figure 2.4.

Monitoring Data Summary

Data collected on Smith Creek and tributaries include VADEQ Ambient Water Quality Monitoring (AWQM) data, VADEQ biomonitoring data, USFS water quality and biomonitoring data, and GMU water quality and biomonitoring data. DEQ AWQM data are typically collected on a monthly basis and biomonitoring data are typically collected in the spring and fall of each year. GMU personnel collected water quality and biomonitoring data on April 25, May 29, July 25, and October 5-6, 2003 (see Table 2.2).

5.4 Stressor Analysis Summary

Selected parameters were plotted to examine spatial trends and to compare impaired and reference stream conditions (Figures 5.1 through 5.15). Water quality monitoring data collected by VADEQ and GMU were analyzed using time-series observation plots presented in this section. Water quality data collected during biomonitoring field visits were not included in these plots. Note that the numbering code for GMU stations in these plots is the same as in Table 5.1. Additionally, some data were available from select USFS sites, which were incorporated into the analysis.

5.4.1 Water Temperature - eliminated stressor

Surface water temperature data for the Smith Creek watershed are shown in Figure 5.1. All observations were below the Class IV maximum criteria (31 degrees Celsius). The single highest observation was recorded at DEQ station 1BDFK000.76, located on Dry Fork. Based on these data, temperature can be eliminated as a possible stressor.

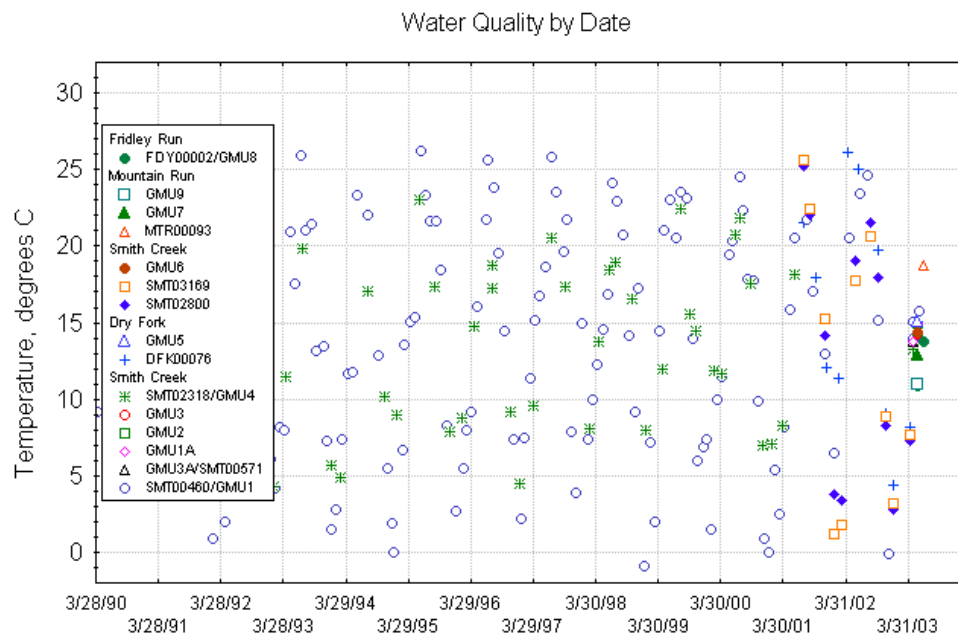


Figure 5.1 Time-series temperature values for Smith Creek watershed stations

5.4.2 pH - eliminated stressor (Smith Creek); most probable stressor (Mountain Run and Fridley Run)

pH data for the Smith Creek watershed are shown in Figure 5.2. All stations, but two, recorded observations within the acceptable range for Class IV waters (6.0-9.0). DEQ/GMU station 1BFDY000.02/GMU8, located on Fridley Run, recorded two observations below 6.0 and DEQ/GMU stations 1BSMT004.60/GMU1 and 1BSMT023.18/GMU4, located on Smith Creek, recorded one observation above 9.0. Station 1BFDY000.02/GMU8 also displayed the greatest fluctuation in pH conditions.

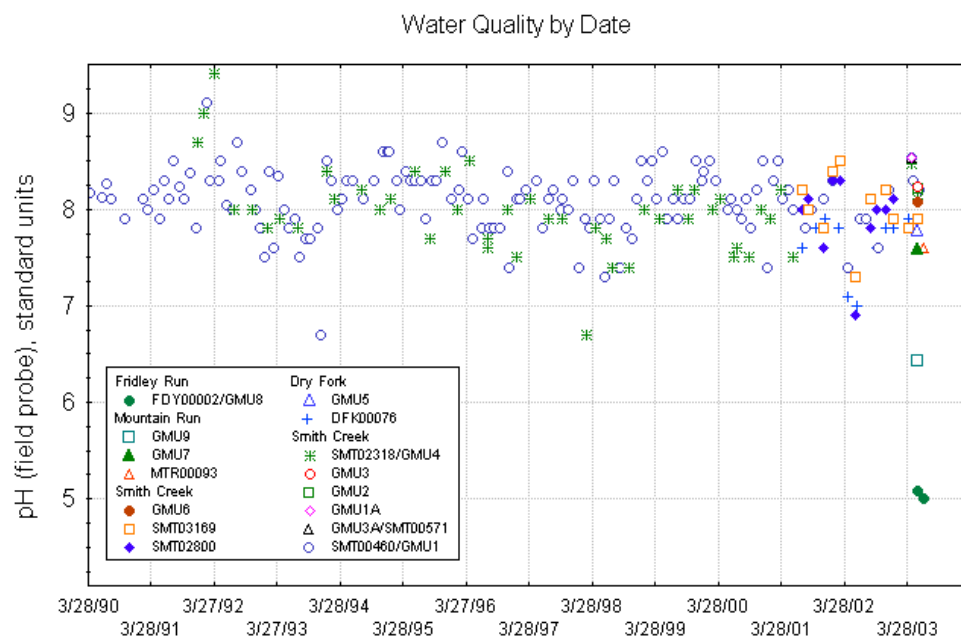


Figure 5.2 Time-series pH values for Smith Creek watershed stations

As part of an ongoing water quality monitoring program in the George Washington National Forest, the U.S. Forest Service conducted a study of pH levels in Mountain Run and Fridley Run. Table 5.1 presents a summary of the data recorded during the study. Both Mountain Run and Fridley Run recorded multiple pH measurements below Virginia's established criteria. In addition, pH conditions in Fridley Run appear to be significantly lower than in Mountain Run. Site 4080, the most upstream site on Fridley Run, recorded the lowest pH of all stations sampled with a maximum pH of 4.78 out of 45 measurements. For stations 4071 and 4074, the majority of the pH measurements below 5.0 were recorded before September 1993. Stations 4074 and 4076 had one pH measurement on January 1, 2002, with all other data collected between October 2, 1992 through December 11, 1996.

Table 5.1 pH measurements for USFS sites in George Washington National Forest

Stream	Site ID	Min pH	Max pH	Mean pH	Number of measurements under pH 6	Total # of observations
Mountain Run	4015	4.61	7.17	6.17	18	51
	4072	4.94	7.23	6.19	16	50
	4073	6.03	7.44	6.86	0	48
	4076	6.8	6.8	6.80	0	1
Fridley Run	4071	4.52	7.34	5.76	30	50
	4074	4.55	7.16	5.70	34	52
	4080	4.43	4.78	4.57	45	45

Based on these data, low pH (acidity) appears to be the primary cause of impairment in Fridley Run and sections of Mountain Run. Stations with low pH measurements include USFS stations 4015 and 4072 on Mountain Run and USFS stations 4071, 4074, and 4080 on Fridley Run. GMU station 7, also located on Mountain Run, had low pH measurements as well. Low pH is the likely cause of the reduction in intolerant organisms such as mayflies and stoneflies at the Mountain Run station. These organisms were found in disproportionately low numbers relative to the population of tolerant organisms (oligochaetes and chironomids) by GMU field researchers. Atmospheric deposition is the likely source of low pH/acidity conditions. TMDLs for these streams will be addressed in a separate report, at a later date, because the impairment cause and source is different than for Smith Creek.

5.4.3 Dissolved Oxygen - eliminated stressor

Primary producers (algae and macrophytes) produce oxygen during the day through photosynthesis and use oxygen at night through respiration. This diel photosynthesis/respiration cycle results in higher DO concentrations during the day and lower concentrations at night. VADEQ and GMU AWQM data collected at Smith Creek watershed stations were compared to the daily average (5.0 mg/L) and minimum (4 mg/L) DO criteria listed in Virginia's Water Quality Standards to help determine if DO conditions are considered to be a primary cause of the benthic impairment. DO concentrations measured at DEQ and GMU monitoring stations were above established criteria (Figure 5.3). The lowest measurements were recorded at DEQ/GMU station 1BSMT004.60/GMU1. Diurnal (24-hour) DO data were not collected by DEQ for this study. Based on these data, low DO was eliminated as a possible cause of impairment.

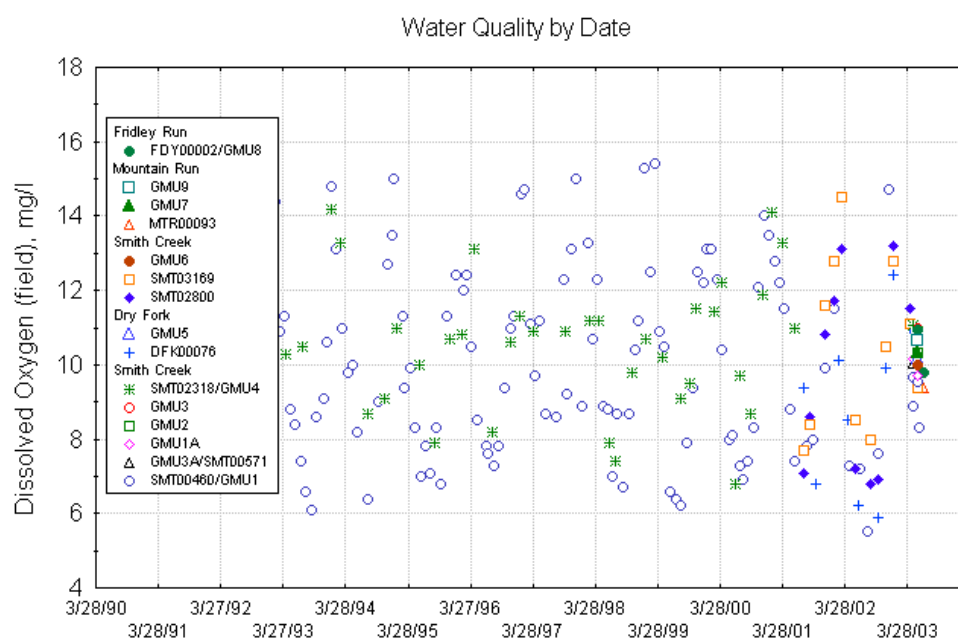


Figure 5.3 Time-series DO values for Smith Creek watershed stations

5.4.4 Organic Matter - possible stressor

Biochemical oxygen demand (BOD5) is the measure of the amount of oxygen consumed by microorganisms during decomposition of organic matter. Therefore, this parameter is a good indicator of the amount of organic matter contributed to a waterbody. BOD5 measurements recorded at all stations show a general grouping within the 1-3 mg/L range (Figure 5.4). Seven observations fell outside of this range. The highest observed values were recorded at DEQ/GMU stations 1BSMT004.60/GMU1 and 1BSMT023.18/GMU4. Data collected on Lacey Spring Branch (1BLAC000.14) are not shown in Figure 5.4

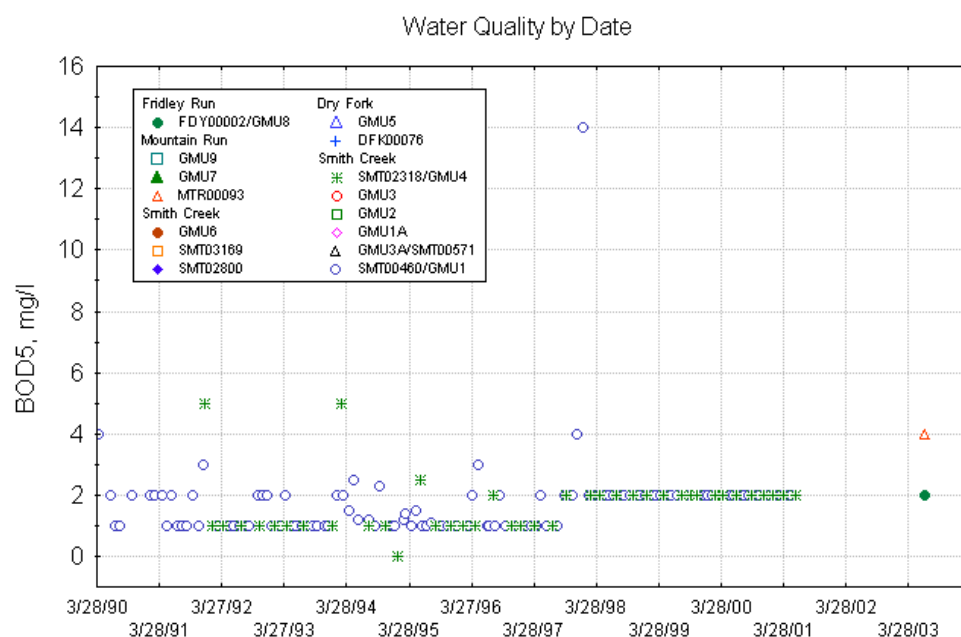


Figure 5.4 Time-series BOD5 values for Smith Creek watershed stations

GMU field crew observed large particulate organic matter concentrations on the bottom substrate during sampling at several stations. In addition, GMU biomonitoring data indicate high numbers of chironomids and hydropsychids in Smith Creek. These families are known to do particularly well in sites with high amounts of particulate organic matter and excessive sedimentation. Overall, these data indicate that organic matter concentrations may be high enough to cause a shift in the benthic community to more tolerant organisms. A TMDL for organic solids was developed for Lacey Spring Branch to primarily address organic contributions from a trout farm located on this stream (VADEQ 2002). Although organic matter is considered a possible stressor, reductions in the contributions from Lacey Spring Branch will lower organic matter inputs to Smith Creek.

5.4.5 Nutrients - possible stressor (Smith Creek); unlikely stressor (Mountain Run and Fridley Run)

Phosphorus

Phosphorus is generally present in waters and wastewaters in different species of soluble (dissolved) and insoluble (particulate or suspended) phosphates, including inorganic (ortho- and condensed) phosphates and organic phosphates. Major sources of phosphorus include detergents, fertilizers, domestic sewage, and agricultural runoff.

Total phosphorus and ortho-phosphate data are presented in Figures 5.5 and 5.6. The majority of the total phosphorus measurements were less than 0.2mg/L, which is the upper limit of the DEQ 305(b) assessment criteria. The exception was DEQ/GMU station 1BSMT004.60/GMU1 which had multiple observations above this threshold level. The lower portion of Smith Creek (15.71 miles, below Lacey Spring Branch) was listed as “threatened” on the 2002 303(d) list due to the high total phosphorus values recorded at this station.

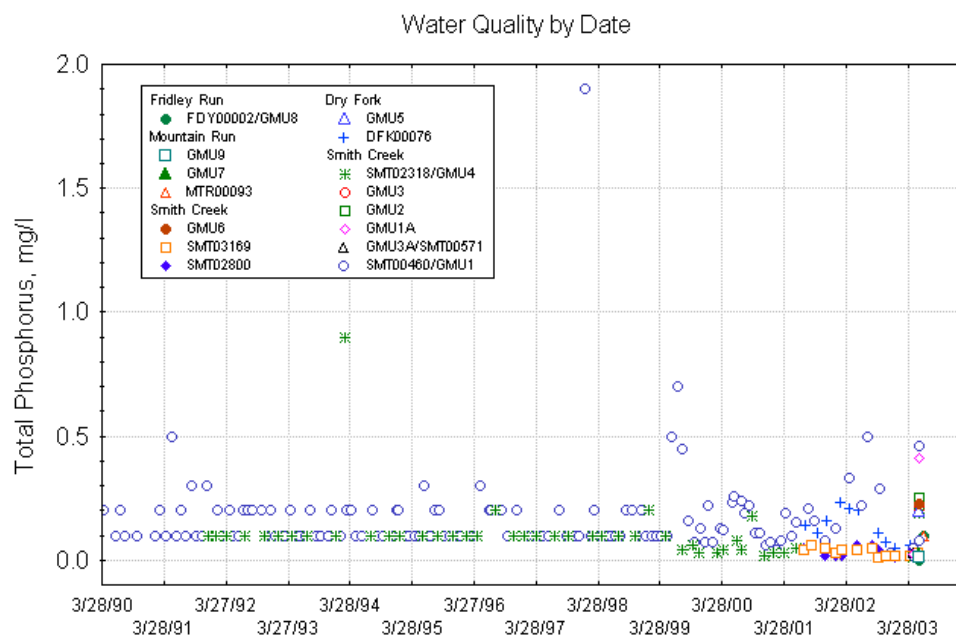


Figure 5.5 Time-series total phosphorus values for Smith Creek watershed stations

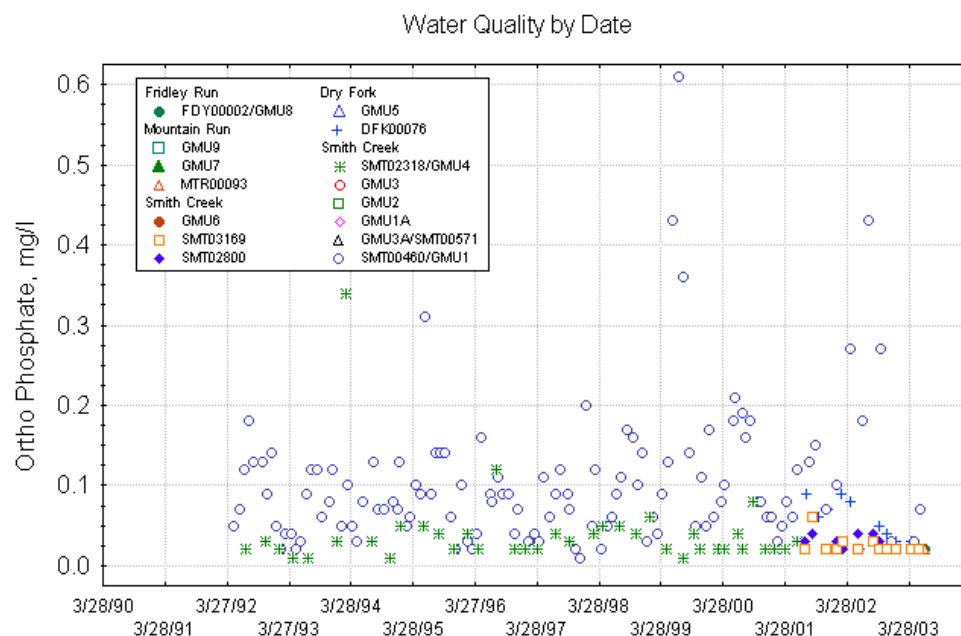


Figure 5.6 Time-series ortho-phosphate values for Smith Creek watershed stations

Nitrogen

Major sources of nitrogen include municipal and industrial wastewater, septic tanks, feed lot discharges, animal wastes, runoff from fertilized agricultural fields and lawns, and discharges from car exhausts. Nitrate and nitrite data are presented in Figures 5.7 through 5.9. These data show a similar pattern with a majority of observations within the following ranges: nitrate 1-3 mg/L and nitrite 0.1-0.3 mg/L. For the data period, DEQ station 1BDFK000.76 consistently showed the most variation registering the second and fourth highest concentrations of both nitrate and nitrite, as well as recording the second, third, and fourth lowest concentrations of nitrate. Smith Creek DEQ/GMU stations 1BSMT004.60/GMU1 and 1BSMT023.18/GMU4 recorded the highest nitrate and nitrite concentrations, respectively.

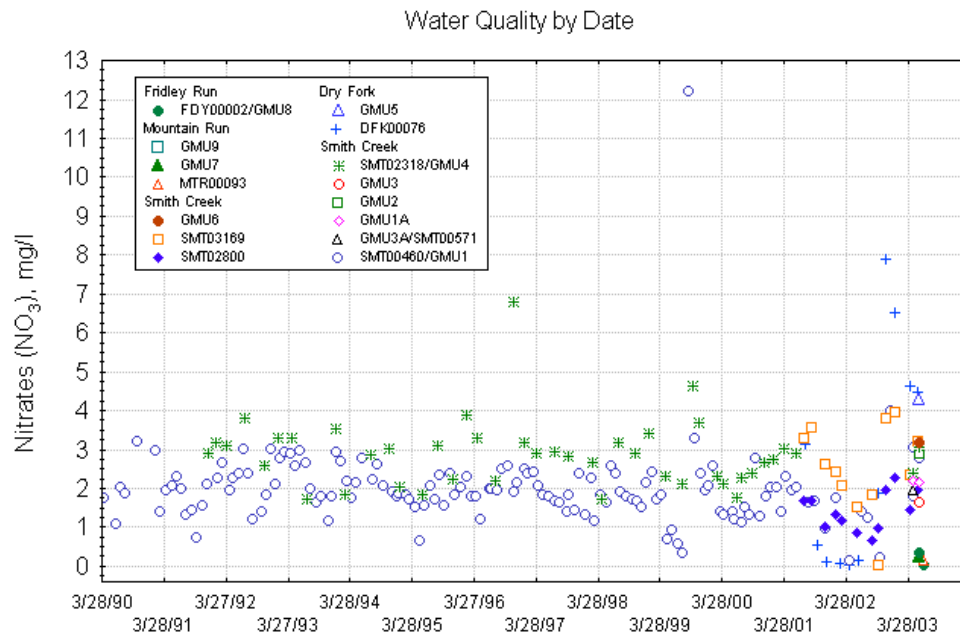


Figure 5.7 Time-series nitrate values for Smith Creek watershed stations

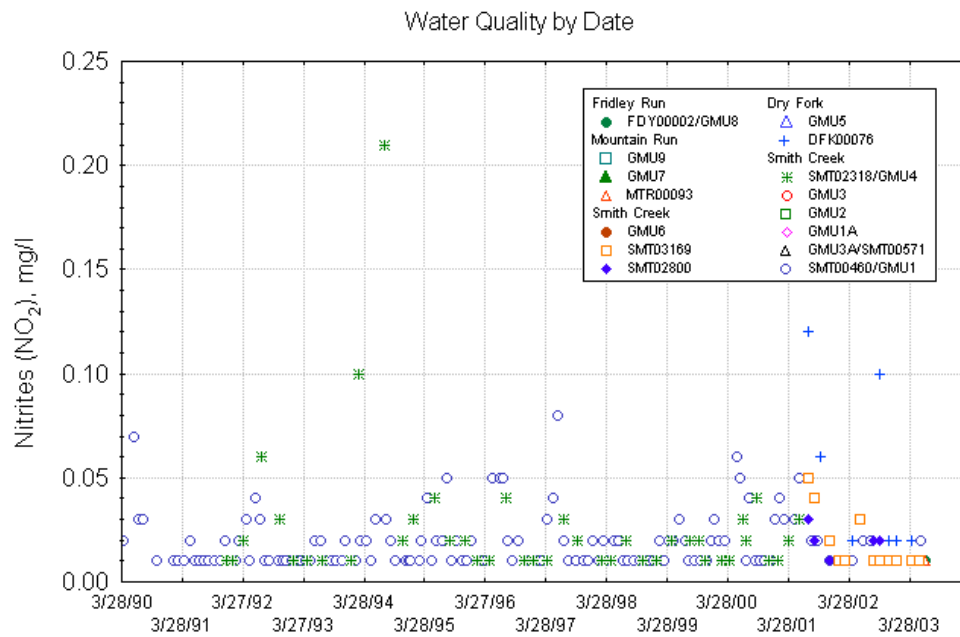


Figure 5.8 Time-series nitrite values for Smith Creek watershed stations

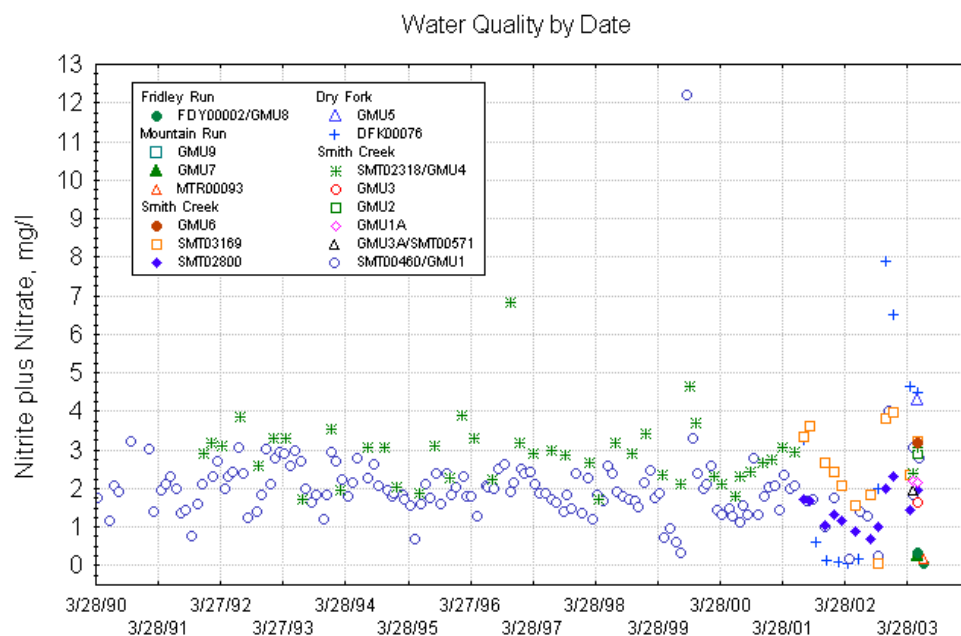


Figure 5.9 Time-series nitrite+nitrate values for Smith Creek watershed stations

TKN and total ammonia data are presented in Figures 5.10 and 5.11. These data show a similar pattern with some of the highest concentrations of both parameters recorded at stations 1BDFK000.76 and 1BSMT004.60. Ammonia is a critical component of the nitrogen cycle. At high concentrations, ammonia is toxic to aquatic life, depending on in-stream pH and temperature levels. In general, higher temperature and pH levels increase the toxicity of ammonia. Virginia's Water Quality Standards (9 VAC 25-260-140) list acute and chronic criteria for ammonia. Ammonia is also discussed in Section 5.4.8 (Toxics).

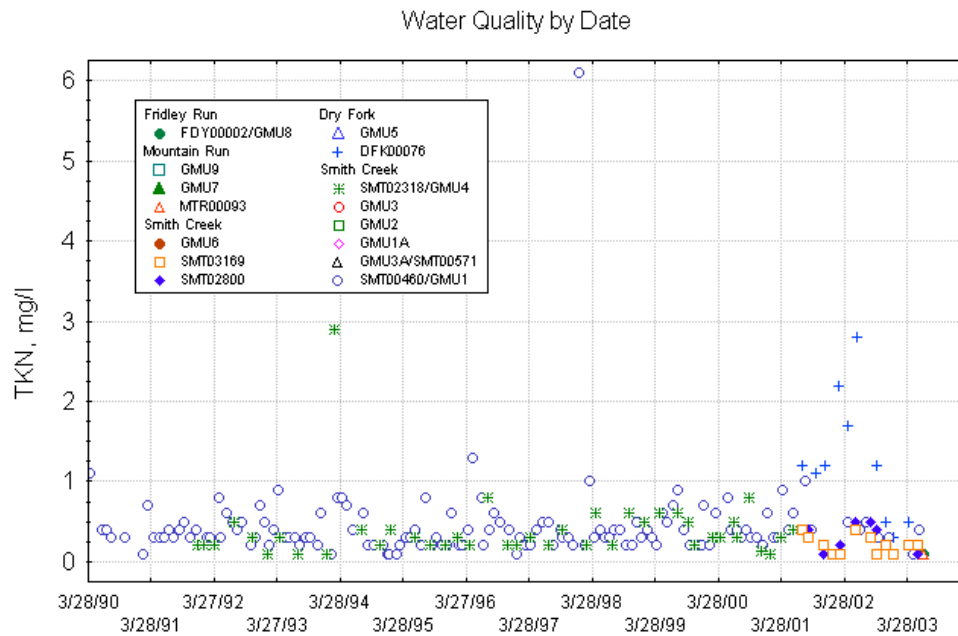


Figure 5.10 Time-series TKN values for Smith Creek watershed stations

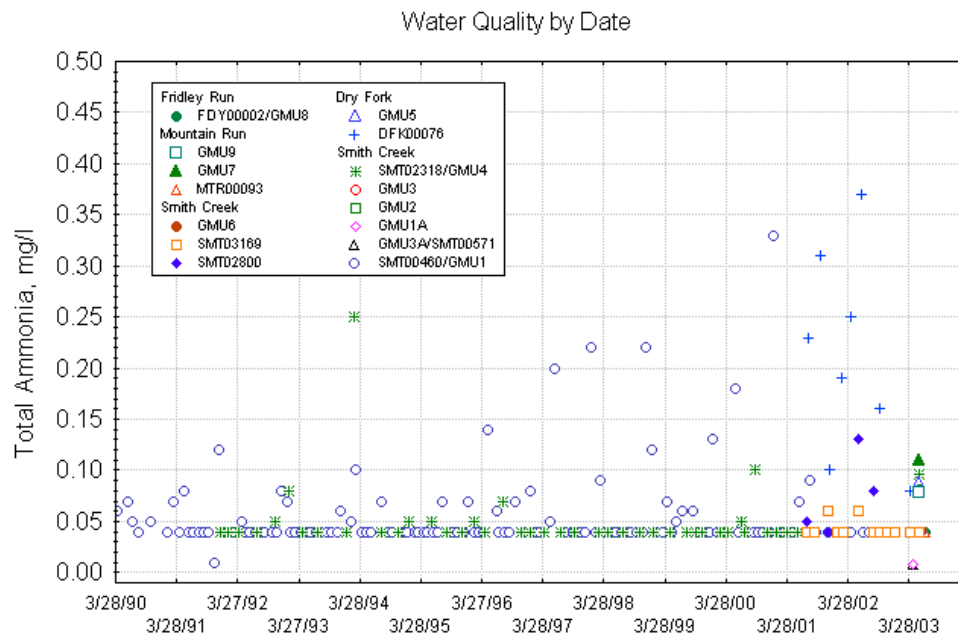


Figure 5.11 Time-series total ammonia values for Smith Creek watershed stations

Nitrogen-Phosphorus Ratios

Nitrogen to phosphorus ratios were calculated using available nutrient data for each monitoring station to determine the limiting nutrient in the Smith Creek watershed. These data are presented in Figure 5.12. The majority of the calculated N:P ratios were above 10, which is generally indicative of a phosphorus-limited stream.

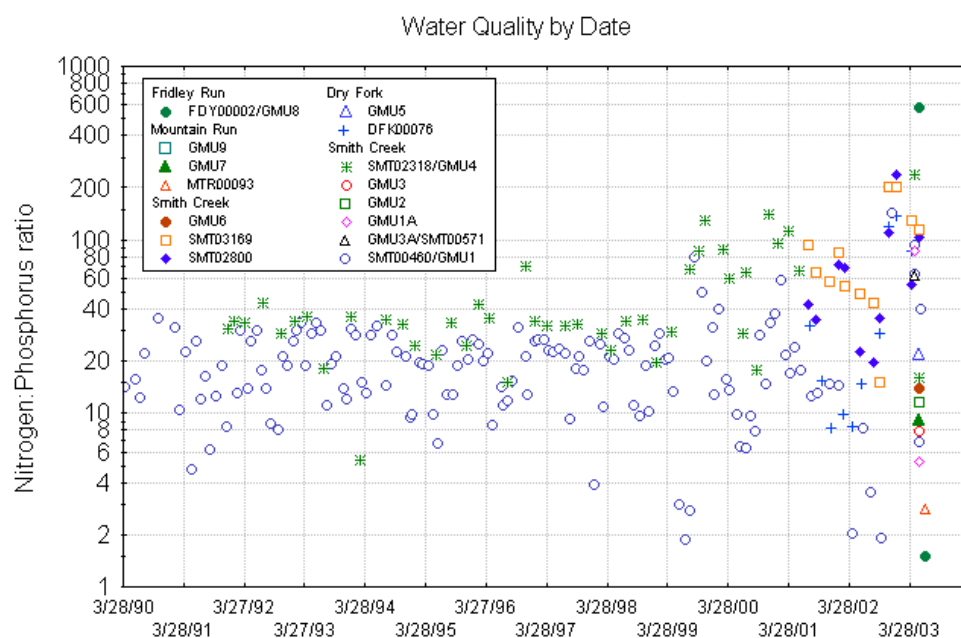


Figure 5.12 Time-series N:P ratios for Smith Creek watershed stations (available nitrogen and phosphorus species data used to calculate N:P ratios)

Based on these data, high nutrient levels are considered to be a possible stressor to the benthic community on Smith Creek. These nutrient levels do not appear to have caused negative impacts to DO and pH conditions in Smith Creek; therefore, the impairment cause pathway (if present) is unclear. As discussed above, the lower portion of Smith Creek (below Lacey Spring Branch) was listed as “threatened” due to high levels of total phosphorus (VADEQ 2002). Reductions associated with the Lacey Spring Branch TMDL should help lower the nutrient contributions to Smith Creek. Mountain Run and Fridley Run do not have high nutrient concentrations. Agricultural production and other possible nutrient sources are limited in the Mountain Run and Fridley Run watersheds.

5.4.6 Sedimentation - most probable stressor (Smith Creek); eliminated stressor (Mountain Run and Fridley Run)

Total Suspended Solids and Turbidity

Total suspended solids (TSS) and turbidity data are presented in Figures 5.13 and 5.14. These sedimentation measurements show a similar pattern with several high observations recorded at various stations on Smith Creek.

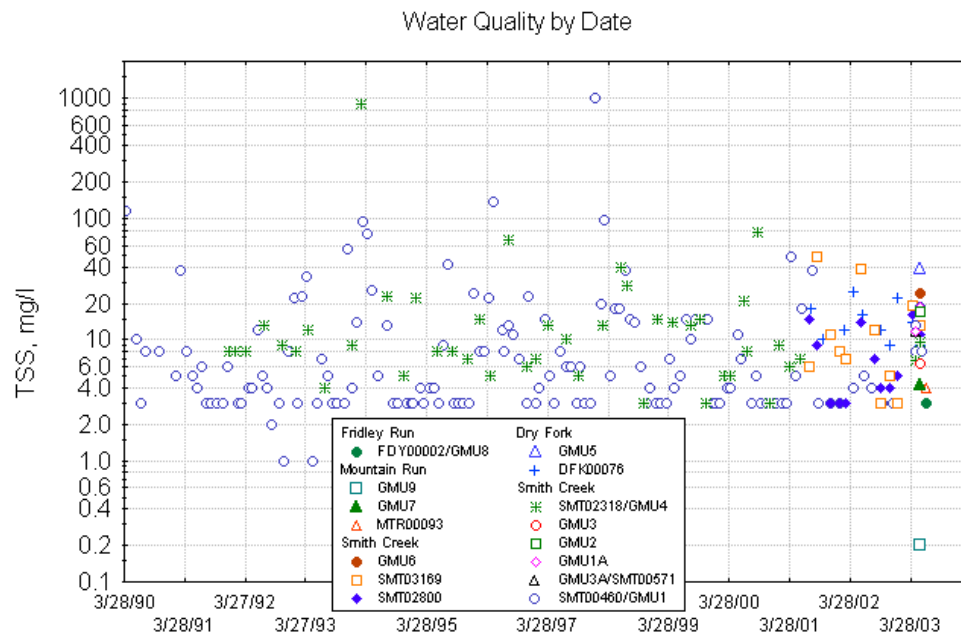


Figure 5.13 Time-series TSS values for Smith Creek watershed stations

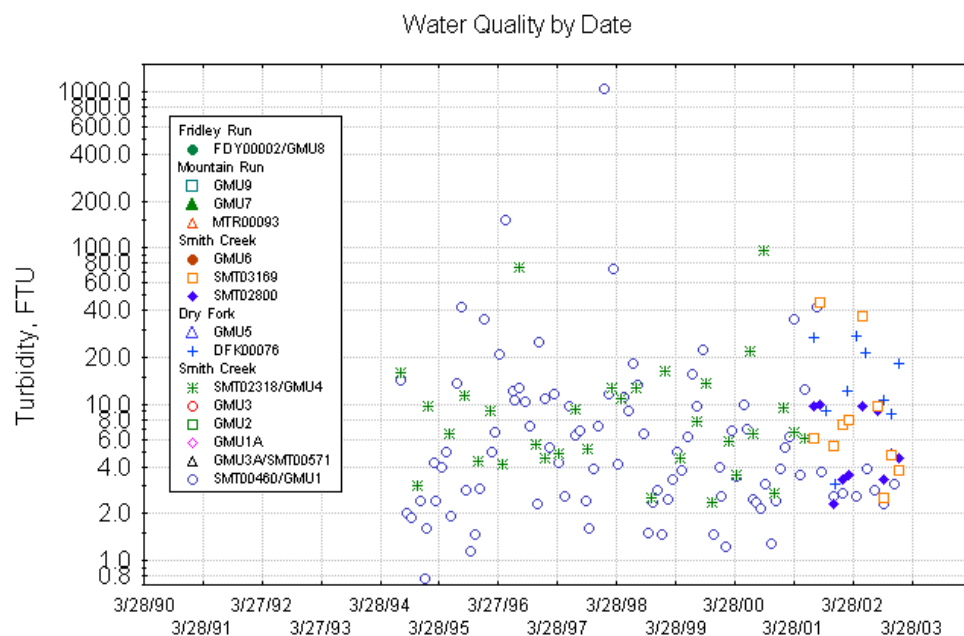


Figure 5.14 Time-series turbidity values for Smith Creek watershed stations

Rapid Bioassessment Protocol - Habitat Data

Rapid Bioassessment Protocol (RBP) habitat data for Smith Creek VADEQ and GMU biomonitoring stations are shown in Tables 5.2 and 5.3. These data were used to examine possible sedimentation and other habitat impacts to the benthic community, along with the TSS and turbidity data discussed above. All habitat scores were evaluated and rated by observation (0-20, with higher scores being better). The following parameters are included in the habitat assessment for the Smith Creek watershed:

- Channel alteration – measure of large-scale changes in the shape of the stream channel
- Bank condition/stability – whether the stream banks are eroded (or have the potential for erosion)
- Bank vegetative protection – the amount of vegetative protection afforded to the stream bank and the near-stream portion of the riparian zone
- Instream cover (for fish)
- Embeddedness – extent to which rocks (gravel, cobble, and boulders) and snags are covered or sunken into the silt, sand, or mud of the stream bottom
- Channel flow status – degree to which the channel is filled with water
- Grazing or other bank disruptive pressure
- Frequency of riffles

- Riparian vegetation zone width – width of natural vegetation from the edge of the stream bank out through the riparian zone
- Sediment deposition – amount of sediment that has accumulated in pools and the changes that have occurred to the stream bottom as a result of deposition
- Epifaunal substrate – relative quantity and variety of natural structures in the stream for spawning and nursery functions of aquatic macrofauna
- Velocity/depth regimes

Table 5.2 RBP habitat scores for the Smith Creek watershed

StationID	Coll Date	Total Habitat Scores	Bank condition	Bank vegetative protection	Channel alteration (anthropocentric)	Channel flow status	Embeddedness of stream	Epifaunal substrate (benthic macroinvertebrate)
SMT005.71	10/05/1994	120	8	10	16	18	8	8
SMT005.71	05/22/1995	164	16	16	16	20	12	12
SMT005.71	09/28/1995	146	14	16	18	20	10	10
SMT005.71	05/23/1996	160	16	14	18	20	12	14
SMT005.71	05/27/1997	144	12	8	16	20	12	14
SMT005.71	09/23/1997	134	16	10	10	20	10	12
SMT005.71	10/20/1998	102	6	9	15	19	10	16
Average		138.57	12.57	11.86	15.57	19.57	10.57	12.29
SMT006.62	05/18/1999	136	15	14	17	20	12	17
SMT006.62	10/14/1999	162	16	18	18	19	16	18
SMT006.62	04/17/2000	148	17	15	17	18	17	15
SMT006.62	11/02/2000	154	14	19	18	18	15	17
SMT006.62	09/27/2001	136	17	15	18	16	11	16
Average		147.20	15.80	16.20	17.60	18.20	14.20	16.60

StationID	Coll Date	Grazing or other bank disruptive pressure	Instream cover	Riffle frequency of stream	Riparian vegetation zone width	Sediment deposition in stream	Velocity-depth regimes of stream
SMT005.71	10/05/1994	8	10	8	4	10	12
SMT005.71	05/22/1995	16	12	12	6	12	14
SMT005.71	09/28/1995	10	12	8	4	12	12
SMT005.71	05/23/1996	10	14	10	6	12	14
SMT005.71	05/27/1997	10	12	8	6	14	12
SMT005.71	09/23/1997	6	12	8	4	10	16
SMT005.71	10/20/1998			3	2	7	15
Average		10.00	12.00	8.14	4.57	11.00	13.57
SMT006.62	05/18/1999			11	3	12	15
SMT006.62	10/14/1999			10	12	18	17
SMT006.62	04/17/2000			10	10	14	15
SMT006.62	11/02/2000			13	7	16	17
SMT006.62	09/27/2001			11	6	8	18
Average				11.00	7.60	13.60	16.40

Table 5.3 GMU RBP habitat scores for the Smith Creek watershed

StationID	CollDate	Total Habitat Score	Epifaunal substrate/ Available cover	Embed-dedness	Velocity/ Depth Regime	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles	Bank Stability	Vegetative Protection	Riparian Vegetative Zone Width
Smith1	5/29/2003	123	14	14	14	14	16	15	15	8	8	5
Smith1A	5/29/2003	130	16	16	15	15	16	15	17	6.5	9	4.5
Smith3	5/29/2003	127.5	15	18	16	13	18	15	13	7.5	7	5
Smith7	5/29/2003	152	19	19	15	18	18	18	20	9	9	7
Smith8	5/29/2003	157.5	20	20	15	17	19	19	19	9	10	9.5

Habitat parameters which provide information on possible sedimentation problems include epifaunal substrate, embeddedness, sediment deposition, epifaunal substrate, and vegetative protection. Smith Creek stations 1, 1A, and 3 had the lowest scores for these parameters, which indicates sedimentation and benthic habitat problems in the stream.

Based on TSS and turbidity data, RBP habitat scores, and field observations by GMU field crew, excessive sedimentation is considered to be the primary stressor to the benthic community in Smith Creek. Mountain Run and Fridley Run do not appear to have sedimentation problems considering the low TSS measurements and high RBP habitat scores recorded at GMU stations 7 and 8.

Note that sediment reductions in the Smith Creek watershed will result in the reduction in nutrients, organic matter, and other pollutants that may be causing water quality and biological problems. Best Management Practices (BMPs) that are typically used to control sediment also help reduce these other pollutants.

5.4.7 Toxics - eliminated stressor (Smith Creek and Mountain Run); possible stressor (Fridley Run)

Toxic Pollutants - Surface Water

Virginia's Water Quality Standards list acute and chronic criteria for surface waters (9 VAC 25-260-140). These numeric criteria were developed for metals, pesticides, and other toxic chemicals which can cause acute and chronic toxicity effects on aquatic life and human health. Available water quality data were compared to these criteria to determine possible effects on aquatic life. Ammonia (NH₃+NH₄) is a critical component of the nitrogen cycle. At high concentrations, ammonia is toxic to aquatic life, depending on pH and temperature levels. In general, the higher the temperature and pH levels, the more toxic ammonia is to aquatic life. Virginia's Water Quality Standards (9 VAC 25-260-155) specify the formulas that are used to calculate the acute and chronic criteria values for ammonia depending on stream type (freshwater or saltwater), temperature, and pH levels, and the expected presence or absence of trout. Ammonia data collected at Smith Creek monitoring stations were compared to the calculated acute and chronic criteria using pH and temperature data collected at the same time. For the period of record at each AWQM station, there were no exceedances noted.

Toxic Pollutants - Sediment

Virginia's Water Quality Standards and updated 305(b) assessment guidance for sediment parameters were consulted to determine if the available data indicate high levels for metals, pesticides, or other constituents that can cause acute or chronic toxicity effects on aquatic life. Sediment data were assessed using EPA Probable Effects Concentration (PEC) thresholds and the NOAA Effects Range-Median (ER-M) and Effects Range-Low (ER-L) screening values. No exceedances were noted for sampled parameters.

EPA Toxicity Testing - acute/chronic toxicity results

A chronic toxicity study was conducted by EPA Region III using fathead minnows (*Pimephales promelas*) and *Ceriodaphnia dubia* (USEPA 2003). The study was conducted on ambient water samples collected from Smith Creek, Mountain Run, and Fridley Run from October 28, 2003 through November 4, 2003. Three sample sites were used for the study: Smith Creek at Rt. 620 Bridge (TMDL #1), Mountain Run at Rt. 620 bridge (TMDL#2), and Fridley Run at Fridley Gap (TMDL #3). Grab samples were collected by VADEQ on October 27, 29, and 31, 2003 and were packed in ice and shipped overnight to EPA's Region III Freshwater Biology Team. The survival/growth of fathead minnows (*Pimephales promelas*) and the survival/reproduction of *Ceriodaphnia dubia* were measured using standard methods. The study concluded that Fridley Run at Fridley Gap had a toxic effect on the minnows (mortality) and affected reproduction in *Ceriodaphnia* (Table 5.4). However, the study concluded that these effects may have been caused by extremely low conductivity, alkalinity and/or hardness (Table 5.5).

Table 5.4 Seven day chronic test results summary in Smith Creek watershed

Site	<i>Ceriodaphnia dubia</i>		<i>Pimephales promelas</i>
	Reproduction (avg).	% survival	% survival
Control	28.7	100	97.5
Smith Creek	31.5	100	92.5
Mountain Run	30.5	94	75
Fridley Run	13.6	100	2.5

Table 5.5 Conductivity data summary from fathead minnow toxicity tests in the Smith Creek watershed

Site	Conductivity (uS/cm)		
	Min	Mean	Max
Control	190	193	196
Smith Creek	500	506	516
Mountain Run	114	118	125
Fridley Run	20	21	22

Surface water, sediment, and EPA toxicity test data do not indicate toxic effects on the benthic community in Smith Creek and Mountain Run. Toxicity test results for Fridley Run showed a toxic response in test organisms. Currently, there are no known sources of toxic pollutants in the Fridley Run watershed, which is entirely forested. It is expected that low pH conditions (see Section 5.4.2) in conjunction with low conductivity, alkalinity, and/or hardness (as mentioned above) are responsible for the toxic response (see Section 5.4.2), unless future monitoring indicates a source of toxic pollutants in the watershed.

5.5 Stressor Conclusions

Station 1BSMT004.60/GMU1 often showed the poorest water quality of all sampling stations in the Smith Creek watershed. This station had the highest BOD5, total phosphorus, orthophosphate, nitrate, TKN, TSS, and turbidity concentrations and recorded the lowest DO level. This station is located in the lower portion of the watershed in a highly agricultural area and downstream of most of the agricultural area within the watershed. Land use in the Smith Creek watershed is shown in Section 2. The watershed primarily consists of pasture/hay land and forest land.

Based on the above analysis, it is hypothesized that excessive sedimentation and organic inputs have caused degraded habitat conditions that are primarily responsible for the benthic impairment in Smith Creek. GMU data indicate lower habitat scores at the DEQ biomonitoring station locations (1BSMT005.71 and 1BSMT006.62) as compared to the upstream GMU sites. These data suggest that sedimentation and other habitat problems are worse in the lower reach, possibly caused by upstream impacts and intensive agricultural utilization in the lower portion of the watershed. Low pH conditions are considered to be primarily responsible for the noted benthic community impairments on Mountain Run and Fridley Run. There is a transition from limestone to shale geology in this area, which decreases the buffering capacity of the stream. Acid deposition and reduced buffering capacity are believed to be responsible for the low pH values observed in Mountain Run and Fridley Run. Nutrient levels do not appear to have caused negative impacts to DO and pH conditions; therefore, nutrient (phosphorus) reductions were not required. Sediment load reductions and the implementation of the Lacey Spring Branch TMDL should reduce nutrients, organic matter inputs, and other pollutants that may be causing water quality and biological problems. Best Management Practices (BMPs) that are typically used to control sediment also help reduce these other pollutants.

SECTION 6

SOURCE ASSESSMENT - SEDIMENT

Point and nonpoint sources of sediment were assessed in TMDL development. The source assessment was used as the basis of model development and analysis of TMDL allocation options. A variety of information was used to characterize sources in impaired and reference watersheds including: MRLC land use/land cover data, water quality monitoring and point source data provided by VADEQ, STATSGO soils data (NRCS), site visit observations, literature sources, and other information. Procedures and assumptions used in estimating sediment sources in impaired and reference watersheds are described in the following sections. Whenever possible, data development and source characterization was accomplished using locally-derived information.

6.1 Assessment of Nonpoint Sources

Erosion of the land results in the transport of sediment to receiving waters through various processes. Factors that influence erosion include characteristics of the soil, vegetative cover, topography, and climate. Nonpoint sources, such as agricultural land uses and construction areas, are large contributors of sediment because the percentage of vegetative cover is typically lower. Urban areas can also contribute quantities of sediment to surface waters through the build-up and eventual washoff of soil particles, dust, debris, and other accumulated materials. Pervious urban areas, such as lawns and other green spaces contribute sediment in the same fashion as low-intensity pasture areas or other similar land uses. In addition, streambank erosion and scouring processes can result in the transport of additional sediment loads.

6.1.1 Agricultural Land

Agricultural land was identified as a primary source of sediment in the Smith Creek watershed. Agricultural runoff can contribute increased pollutant loads when farm management practices allow soils rich in nutrients from fertilizers or animal waste to be washed into the stream, increasing in-stream sediment levels. The erosion potential of cropland and over-grazed pasture land is particularly high due to the lack of year-round vegetative cover. The use of cover crops and other management practices have been shown to reduce the transport of pollutant loads from agricultural lands.

The MRLC land use coverage for the Smith Creek watershed is shown in Figure 2.1.

6.1.2 Forest Land

Agricultural and urban development in this watershed has replaced some mature forest areas, especially along the stream and at lower elevations. The sediment yield from undisturbed forest lands, especially during the growing season, is low due to the amount of dense vegetative cover, which stabilizes soils and reduces rainfall impact.

6.1.3 Urban Areas

Urban land uses represented in the MRLC land use coverage include commercial, industrial, transportation, and residential areas. Urban land uses consist of pervious and impervious areas. Stormwater runoff from impervious areas, such as paved roads and parking lots, contribute pollutants that accumulate on these surfaces directly to receiving waters without being filtered by soil or vegetation. Sediment deposits in impervious areas originate from vehicle exhaust, industrial and commercial activities, outdoor storage piles, and other sources. In addition, stormwater runoff can cause streambank erosion and bottom scouring through high flow volumes, resulting in increased sedimentation and other habitat impacts.

The primary urban sources of sediment are construction sites and other pervious lands. Construction sites have high erosion rates due to the removal of vegetation and top soil. Typical erosion rates for construction sites are 35 to 45 tons per acre per year as compared to 1 to 10 tons per acre per year for cropland. Residential lawns and other green spaces contribute sediment in the same fashion as low-intensity pasture areas or other similar land uses.

Urban land use areas were separated into pervious and impervious fractions based on the estimated percent impervious surface of each urban land use category. Field observations and literature values were used to determine the effective percent imperviousness of urban land uses (Table 6.1).

Table 6.1 Percent imperviousness of urban land uses

Urban land uses	Percent impervious
High Intensity Residential	40%
Low Intensity Residential	10%
High Intensity Commercial/Industrial/Transportation	50%

6.2 Assessment of Point Sources

Point sources can contribute sediment loads to surface waters through effluent discharges. These facilities are permitted through the Virginia Pollutant Discharge Elimination System (VPDES) program that is managed by VADEQ. There are currently 38 point source permits in the Smith Creek watershed (Table 6.2), including a Municipal Separate Storm Sewer System (MS4) permit that was issued to the City of Harrisonburg to help control impacts caused by stormwater runoff from urban areas (VPDES # VAR040075). All of these facilities potentially discharge sediment to streams in the Smith Creek watershed.

Sediment loads contributed by each facility were calculated based on the type of VPDES permit (individual, general, stormwater, MS4) and the current permit conditions. The sediment load contributed by individual and general permits was calculated based on the permitted flow (1000 gallons/day for general permits) and the applicable TSS limit (typically 30 mg/L for general permits). Stormwater permit loads were calculated using a threshold TSS value of 100 mg/l and the estimated average annual runoff for the permitted area (based on modeling results). The sediment load contributed by the MS4 permit during runoff events was calculated based on the modeling results for urban lands located within the City of Harrisonburg and the Smith Creek watershed.

Table 6.2 VPDES permitted facilities in the Smith Creek watershed

VPDES Permit No.	Facility Name	Receiving Stream
VA0027626	Valley View Mobile Home Court	Dry Fork X Trib
VA0054453	New Market Poultry Products	Smith Creek
VA0071846	Endless Caverns Inc	Smith Creek X Trib
VA0080535	Two Hills Inc STP	Smith Creek
VA0077399	Lacey Spring Elementary School STP	Lacey Spring, U.T.
VA0090794	Holtzman Express-Mauzy	Smith Creek
VA0091235	Shenandoah Fisheries, Ltd	Lacey Spring
VA0088994	Harrisonburg-New Market KOA	War Branch
VA0083305	Camp Overlook	Mountain Run
VAG408049	Private Residence	Smith Creek, UT
VAG401001	Private Residence	Smith Creek
VAG401128	Private Residence	Smith Creek, U.T.
VAG401201	Private Residence	Smith Creek
VAG401179	Private Residence	Smith Creek, U.T.
VAG401363	Private Residence	Smith Creek, U.T.
VAG401492	Private Residence	Smith Creek, U.T.
VAG401537	Private Residence	Smith Creek, U.T.
VAG401551	Private Residence	Smith Creek, U.T.
VAG401405	Private Residence	Smith Creek, U.T.
VAG401890	Private Residence	War Branch
VAG401956	Private Residence	Smith Creek, U.T.
VAG401966	Private Residence	Smith Creek UT
VAG401961	Private Residence	Smith Creek UT
VAG401805	Private Residence	Smith Creek, U.T.
VAG401920	Private Residence	Smith Creek, UT
VAG401432	Private Residence	Smith Creek
VAG401988	Private Residence	Smith Creek, U.T.
VAG401998	Private Residence	Smith Creek, U.T.
VAG408026	Private Residence	Dry Fork, U.T.
VAG408028	Private Residence	Smith Creek, U.T.
VAG408029	Private Residence	Smith Creek, U.T.
VAG408030	Private Residence	Smith Creek, U.T.
VAG408035	Private Residence	Smith Creek, U.T.
VAG110131	Superior Concrete Central Plant	Quarry in Smith Creek watershed
VAR100591	Rockingham Redi-Mix Inc	Dry Fork, UT
VAR102386	Holtzman Express-Mauzy	Smith Creek, UT
VAR051331	Harper's Lawn Ornaments	Dry Fork, UT
VAR040075	City of Harrisonburg MS4	N/A

SECTION 7

WATERSHED MODELING - SEDIMENT

7.1 Reference Watershed Approach

7.1.1 Background

Biological communities respond to any number of environmental stressors, including physical impacts and changes in water and sediment chemistry. According to the 2002 303(d) Fact Sheet for Smith Creek, agricultural runoff was identified as the likely source of the benthic impairment.

TMDL development requires the identification of impairment causes and the establishment of numeric endpoints that will allow for the attainment of designated uses and water quality criteria. Numeric endpoints represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. Virginia does not currently have numeric criteria for nutrients (i.e., total phosphorus and total nitrogen), sediment, and other parameters that may be contributing to the impaired condition of the benthic community in this stream. A reference watershed approach was, therefore, used to determine the primary benthic community stressors and to establish numeric endpoints for these stressors. This approach is based on selecting non-impaired watersheds that share similar land use, ecoregion, and geomorphological characteristics with the impaired watershed. Stream conditions in the reference watershed are assumed to be representative of the conditions needed for the impaired stream to attain its designated uses. The Virginia Stream Condition Index (VaSCI) was used to define differences in the benthic communities in impaired and reference streams (USEPA 2003). Loading rates for pollutants of concern are determined for impaired and reference watersheds through modeling studies. Both point and nonpoint sources are considered in the analysis of pollutant sources and in watershed modeling. Numeric endpoints are based on reference watershed loadings for pollutants of concern and load reductions necessary to meet these endpoints are determined. TMDL load allocation scenarios are then developed based on an analysis of the degree to which contributing sources can be reasonably reduced.

7.1.2 Reference Watershed Selection

The reference watershed selection process is based on a comparison of key watershed, stream and biological characteristics. The goal of the process is to select one or several similar, unimpaired reference watersheds that can be used to identify benthic community stressors and develop TMDL endpoints. Reference watershed selection was based on the results of VADEQ biomonitoring studies and comparisons of key watershed characteristics. Data used in the reference watershed selection

process for the Smith Creek watershed are shown in Table 7.1.

Table 7.1 Reference watershed selection data

Biomonitoring Data	Ecoregion Coverages
Topography	Land use Distribution
Soils	Watershed Size
Water Quality Data	Point Source Inventory

Tetra Tech, VADEQ, and USEPA recently developed the Virginia Stream Condition Index (VaSCI), which provides a more detailed and reliable assessment of the benthic macroinvertebrate community in Virginia's non-coastal, wadeable streams (USEPA 2003). This new multi-metric index, was used to compare relative differences in the benthic community between impaired and reference streams. This index allows for the evaluation of biological condition as a factor in the reference watershed selection process and can be used to measure improvements in the benthic macroinvertebrate community in the future. VADEQ biomonitoring data were used to calculate the VaSCI scores shown in Table 7.2.

Table 7.2 Bioassessment index scores for Smith Creek

StationID	Organization	Stream	Location	Sample Date	VaSCI Index Score
SMT005.71	DEQ	Smith Creek	Downstream of Rt. 620 bridge	10/05/1994	52
				05/22/1995	72
				09/28/1995	64
				05/23/1996	57
				05/27/1997	56
				09/23/1997	63
				10/20/1998	71
Average					62
SMT006.62	DEQ	Smith Creek	Rt. 620 bridge	05/18/1999	60
				10/14/1999	68
				04/17/2000	57
				11/02/2000	71
				09/27/2001	48
Smith1A	GMU	Smith Creek		05/29/2003	44
Average					58
Smith1	GMU	Smith Creek	At Rt. 616, DEQ station 1BSMT004.60	05/29/2003	56
Smith2	GMU	Smith Creek	At Rt. 794	07/25/2003	45
Smith4	GMU	Smith Creek	At Rt. 608, DEQ station 1BSMT023.18	07/25/2003	41
Smith7	GMU	Mountain Run	At Mt. Valley Rd.	05/29/2003	53
Smith8	GMU	Fridley Run	Just above confluence w/Mountain Run ext.	05/29/2003	53
Smith9	GMU	Mountain Run ext.	Just above confluence w/Fridley Run	05/29/2003	70
Overall Average					58

7.1.3 Selected Reference Watershed

The Hays Creek watershed, delineated at the VADEQ biomonitoring station, was selected as the reference for this TMDL study (Figure 7.1). This determination was based on the degree of similarity between this stream and its associated watershed to the impaired stream and the results of the VaSCI scores. Figures 7.2, 7.3, and 7.4 show comparisons of the MRLC land use, soils, and ecoregion distributions within the Smith Creek watershed and the Hays Creek watershed.

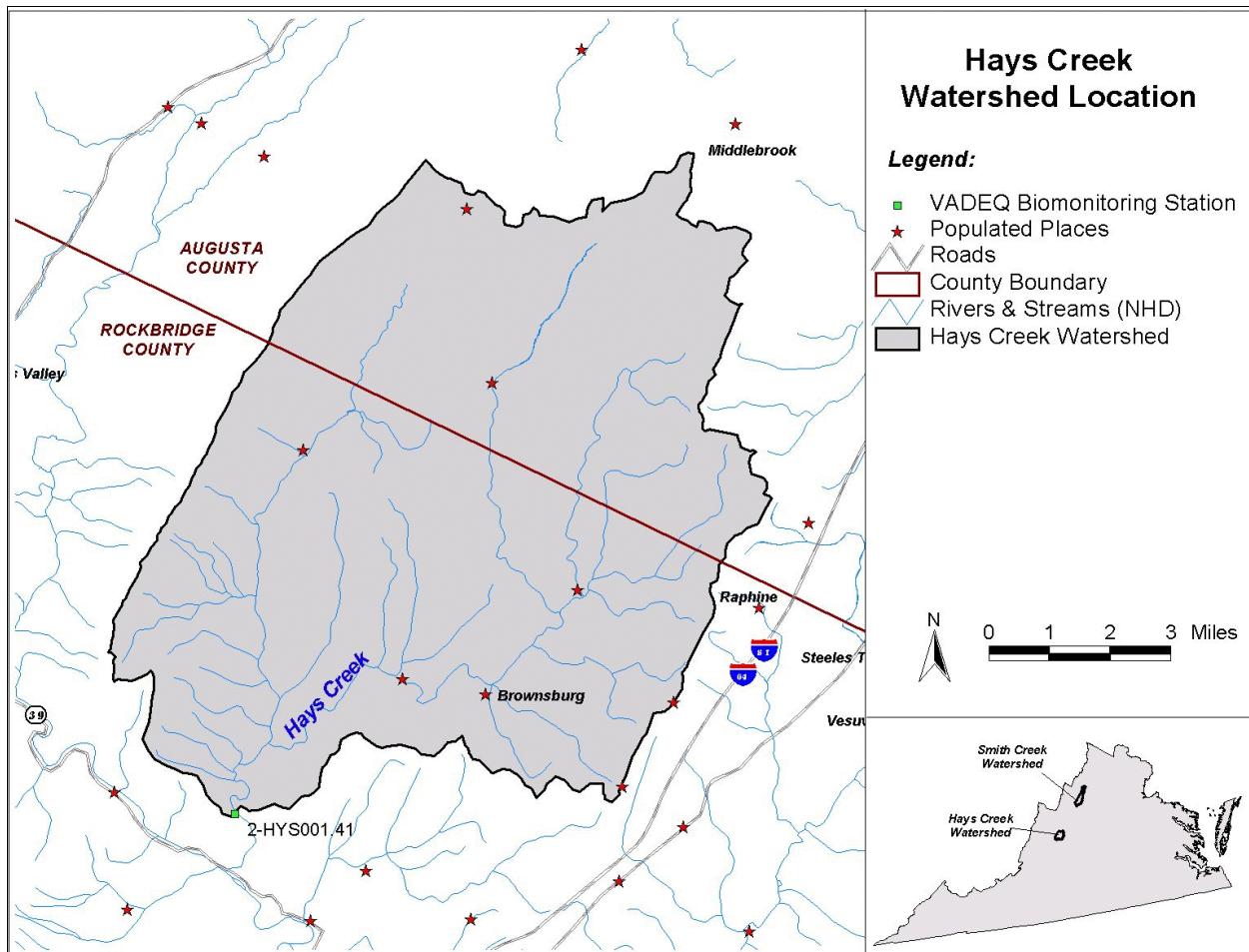


Figure 7.1 Hays Creek watershed location and monitoring stations

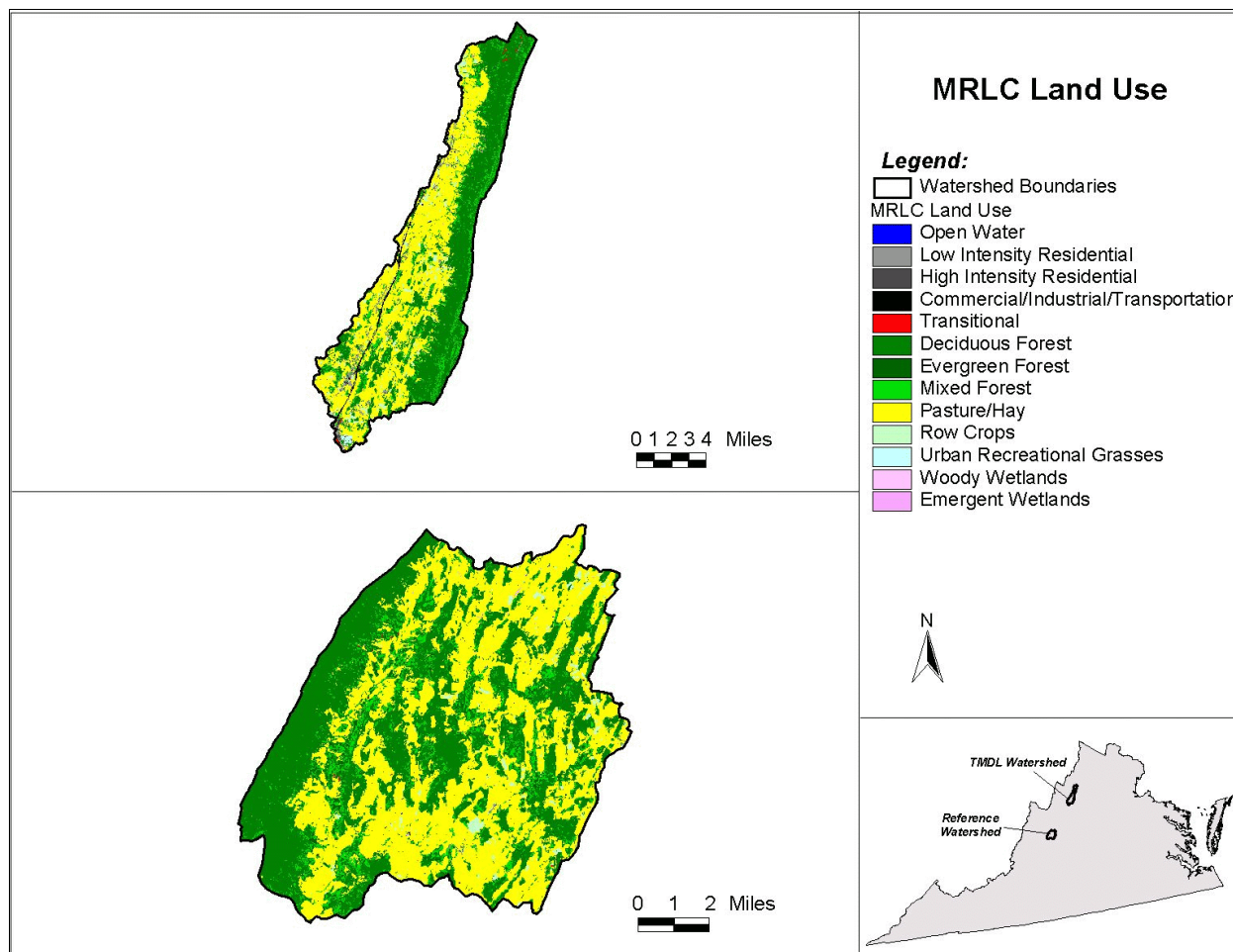


Figure 7.2 MRLC land use in the impaired and reference watersheds

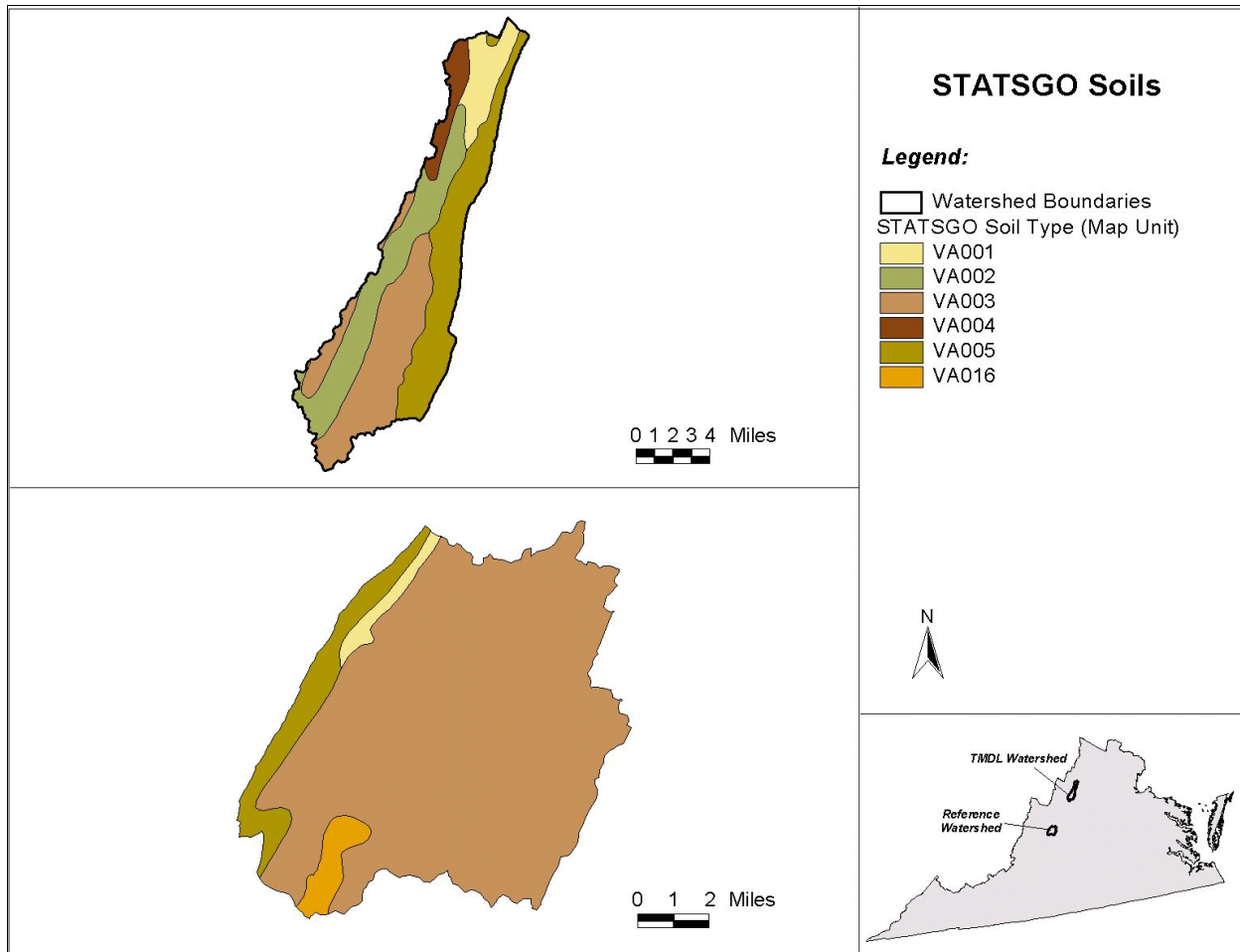


Figure 7.3 STATSGO soil types in the impaired and reference watersheds

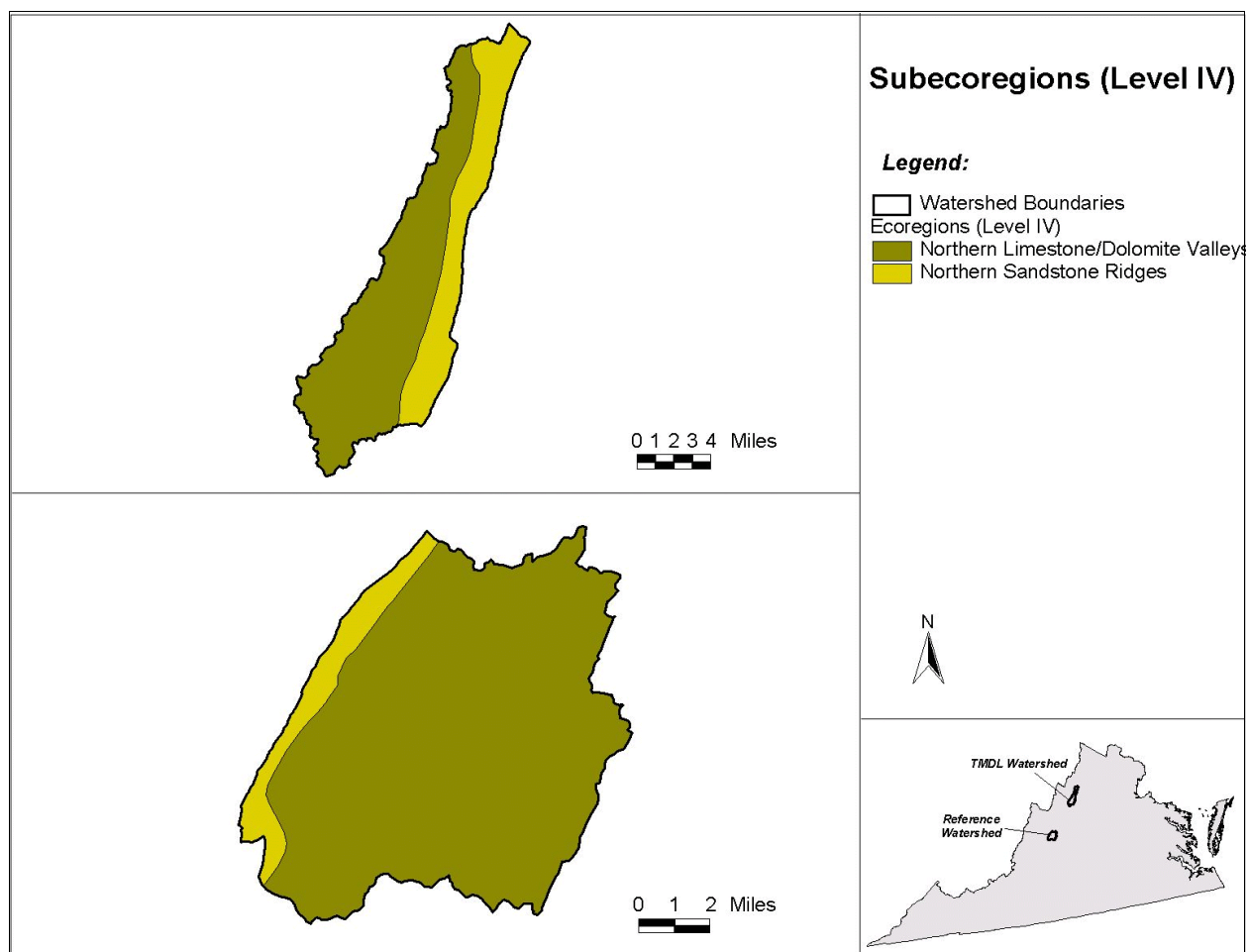


Figure 7.4 Level IV ecoregions in the impaired and reference watersheds

7.2 Watershed Model

TMDLs were developed using BasinSim 1.0 and the GWLF model (Dai et al. 2000). The GWLF model, which was originally developed by Cornell University (Haith and Shoemaker 1987, Haith et al. 1992), provides the ability to simulate runoff, sediment, and nutrient loadings from watersheds given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads, and allows for the inclusion of point source discharge data. GWLF is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on daily water balance totals that are summed to give monthly values.

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios. Each area is assumed to be homogenous with respect to various attributes considered by the model. Additionally, the model

does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover/soil type combination). The KLSCP factors are variables used in the calculations to depict changes in soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P). A sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff are applied to the calculated erosion to determine sediment yield for each source area. Point source discharges also can contribute to loads to the stream. Evapotranspiration is determined using daily weather data and a cover factor dependent on land use/cover type. Finally, a water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. All of the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker 1987) and GWLF User's Manual (Haith et al. 1992).

Slight modifications were made to the GWLF model in order to include sediment loads from lands classified as impervious urban areas. The inclusion of these loads is based on sediment accumulation and washoff functions. A sediment accumulation rate of 2.8 kg/ha-day was used to represent the urban lands in the Smith Creek and Hays Creek watersheds.

For execution, the model requires three separate input files containing transport, nutrient, and weather-related data. The transport file (TRANSPRT.DAT) defines the necessary parameters for each source area to be considered (e.g., area size, curve number) as well as global parameters (e.g., initial storage, sediment delivery ratio) that apply to all source areas. The nutrient file (NUTRIENT.DAT) specifies the various loading parameters for the different source areas identified (e.g., number of septic systems, urban source area accumulation rates, manure concentrations). The nutrient file is necessary for the model to run but is not used in any of the calculations. The weather file (WEATHER.DAT) contains daily average temperature and total precipitation values for each year simulated.

7.3 Model Setup

Watershed data needed to run the GWLF model in BasinSim 1.0 were generated using GIS spatial coverages, water quality monitoring and streamflow data, local weather data, literature values, and

other information. The Smith Creek watershed and reference watershed were delineated based on hydrologic and topographic data (USGS 7.5 minute digital topographic maps (24K DRG - Digital Raster Graphics)), and the location of DEQ monitoring stations. The outlet of the Smith Creek watershed is the downstream limit of the impaired segment, which is also the mouth. The reference watershed outlet is located at the VADEQ biomonitoring station on Hays Creek. To equate target and reference watershed areas for TMDL development, the total area for the reference watershed was reduced to be equal to the area of the Smith Creek watershed, after hydrology calibration. To accomplish this, land use areas (in the reference watershed) were proportionally reduced based on the percent land use distribution.

Local rainfall and temperature data were used to simulate flow conditions in modeled watersheds. Daily precipitation and temperature data were obtained from local National Climatic Data Center (NCDC) weather stations. The weather stations and data periods that correspond with the modeled watersheds are shown in Table 7.3. The periods of record selected for model calibration runs (April 1, 1990 through September 30, 2002 for the Smith Creek model and April 1, 1991 through March 31, 1997 for the reference model) were based on the availability of recent weather data and corresponding streamflow records. The weather data collected at the NCDC station of Dale Enterprise (precipitation and temperature data) were used to construct the weather file used in the Smith Creek watershed simulation. Hays Creek modeling was based on precipitation data collected at the NCDC station on Kerrs Creek and temperature data collected at the NCDC station in nearby Lexington, Virginia. The calculated daily average temperatures for Lexington were reduced by one degree Celcius to adjust for the difference in elevation between Lexington and the Hays Creek watershed.

Table 7.3 Weather stations used in GWLF models

Watershed	Weather Station	Data Type	Data Period
Smith Creek	Dale Enterprise	Daily Precipitation	4/1/90 - 12/31/02
		Daily Temperature	4/1/90 - 12/31/02
Hays Creek	Kerrs Creek	Daily Precipitation	4/1/90 - 3/31/97
	Lexington	Daily Temperature	4/1/90 - 3/31/97

Daily streamflow data are needed to calibrate watershed hydrologic parameters in the GWLF model. The USGS gage station located on Smith Creek near New Market, Virginia was used to calibrate the Smith Creek watershed. The Hays Creek watershed hydrology was calibrated using flow data from the gaging station on Kerrs Creek near Lexington, Virginia. Table 7.4 lists the USGS gaging stations along with the period of record used for the watersheds.

Table 7.4 USGS gaging stations used in GWLF models

Modeled Watershed	USGS station number	USGS gage location	Data Period
Smith Creek	1632900	Smith Creek near New Market, VA	4/1/90 - 9/30/02
Hays Creek	2022500	Kerrs Creek near Lexington, VA	4/1/90 - 3/31/97

7.4 Explanation of Important Model Parameters

In the GWLF model, the nonpoint source load calculation is affected by terrain conditions, such as the amount of agricultural land, land slope, soil erodibility, farming practices used in the area, and by background concentrations of nutrients (nitrogen and phosphorus) in soil and groundwater. Various parameters are included in the model to account for these conditions and practices. Some of the more important parameters are summarized as follows:

Areal extent of different land use/cover categories: The MRLC land use coverage was used to calculate the area of each land use category in impaired and reference watersheds, respectively.

Curve number: This parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use/cover and hydrologic soil type and is calculated directly using digital land use and soils coverages. Soils data for both the impaired and reference watersheds were obtained from the State Soil Geographic (STATSGO) database for Virginia, developed by NRCS.

K factor: This factor relates to inherent soil erodibility, and it affects the amount of soil erosion taking place on a given unit of land. The K factor and other Universal Soils Loss Equation (USLE) parameters were downloaded from the NRCS Natural Resources Inventory (NRI) database (1992). Average values for specific crops/land uses in each watershed county were used (Shenandoah and Rockingham counties). The predominant crop grown in this watershed is corn; therefore, cropland values were based on data collected in corn crops.

LS factor: This factor signifies the steepness and length of slopes in an area and directly affects the amount of soil erosion.

C factor: This factor is related to the amount of vegetative cover in an area. In agricultural areas, this factor is largely controlled by the crops grown and the cultivation practices used. Values range from 0 to 1.0, with larger values indicating a higher potential for erosion.

P factor: This factor is directly related to the conservation practices used in agricultural areas. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion.

Sediment delivery ratio: This parameter specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size.

Unsaturated available water-holding capacity: This parameter relates to the amount of water that can be stored in the soil and affects runoff and infiltration.

Other less important factors that can affect sediment loads in a watershed also are included in the model. More detailed information about these parameters and those outlined above can be obtained from the GWLF User's Manual (Haith et al. 1992). Pages 15 through 41 of the manual provide specific details that describe equations and typical parameter values used in the model.

7.5 Hydrology Calibration

Using the input files created in the BasinSim 1.0, GWLF predicted overall water balances in impaired and reference watersheds. As discussed in Section 7.3, the modeling period is determined based on the availability of weather and flow data that were collected during the same time period. The Smith Creek watershed was calibrated for a period of eleven and a half years from 4/1991 to 9/2002 using the stream flow data from USGS gage 01632900 on Smith Creek. The Hays Creek watershed (reference watershed) was calibrated for a period of six years from 4/1991 to 3/1997 using the stream flow data from the nearby USGS gage 02022500 on Kerrs Creek near Lexington. USGS gage locations do not coincide with the outlet (pour point) of each modeled watershed; therefore, stream flow measurements were normalized by area to facilitate calibration. Calibration statistics are presented in Table 7.5. In general, an R^2 value greater than 0.7 indicates a strong, positive correlation between simulated and observed data. These results indicate a good correlation between simulated and observed results for these watersheds. A total flow volume error percentage of less than 2% was achieved in calibration of the model for each watershed. In general, the seasonal trends and peaks are captured reasonably well for the twelve and seven year periods in the impaired and reference watersheds, respectively. Hydrology calibration results and the modeled time period for the impaired and the reference watersheds are given in Figures 7.5 and 7.6. Differences between observed and modeled flows are likely due to inherent errors in flow estimation procedures based on normalization for watershed size and the proximity of the selected weather stations to each modeled watershed and the corresponding USGS gage.

Table 7.5 GWLF flow calibration statistics

Modeled Watershed	Simulation Period	R2 (Correlation) Value	Total Volume % Error
Smith Creek	4/1/91 - 9/30/02	0.7445	2%
Hays Creek	4/1/91 - 3/31/97	0.7919	2%

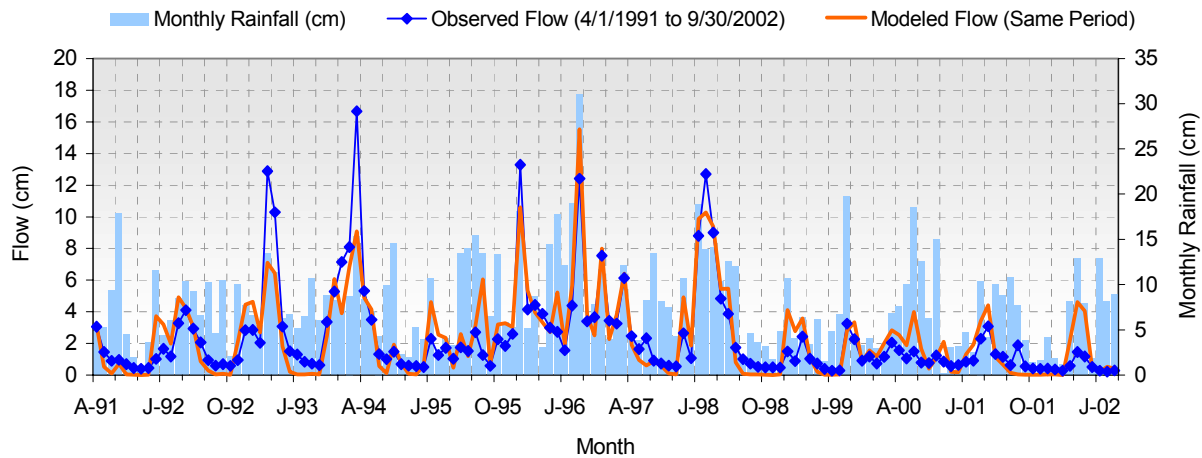


Figure 7.5 Smith Creek hydrology calibration using USGS gage 01632900

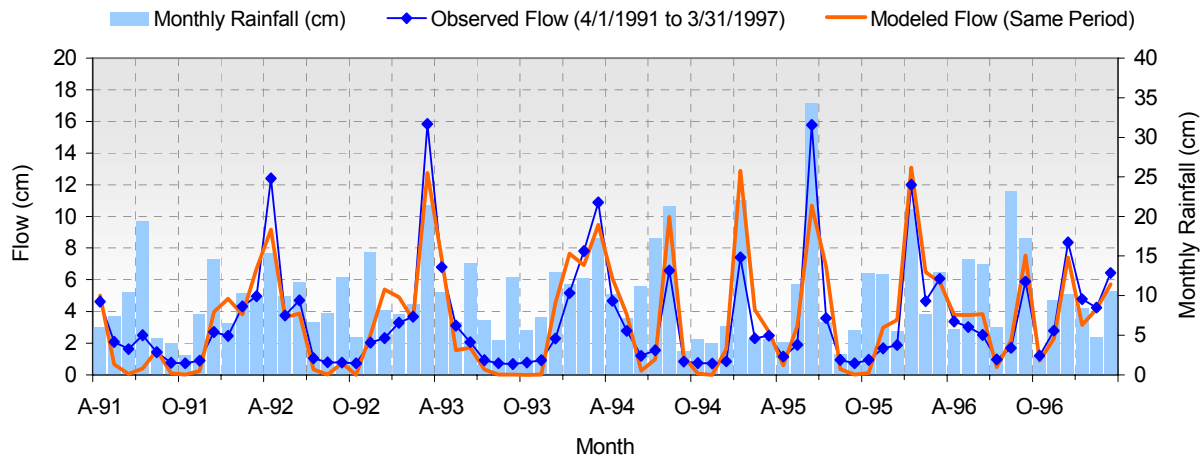


Figure 7.6 Hays Creek hydrology calibration using USGS gage 02022500

SECTION 8

TMDL METHODOLOGY - BACTERIA

8.1 TMDL Calculation

The *E. coli* bacteria TMDL established for Smith Creek consists of a point source waste load allocation (WLA), a nonpoint source load allocation (LA), and a margin of safety (MOS). The TMDL is the total amount of a pollutant that can be assimilated by the receiving waterbody while still achieving water quality standards. For *E. coli*, TMDLs are expressed in terms of bacteria counts (or resulting concentration).

The TMDL equation is as follows:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

The WLA portion of this equation is the total loading assigned to point sources (e.g., sewage treatment plants or municipal separate storm sewer system (MS4) permits). The LA portion represents the loading assigned to nonpoint sources (e.g., failing septic discharges, cattle direct deposition). The MOS accounts for any uncertainty in the data and the modeling process. Implicit MOS factors were incorporated into the TMDL development process through the use of conservative model assumptions and source load estimates.

8.2 Wasteload Allocations

There are currently 38 point source permits in the Smith Creek watershed (Table 8.1), including a Municipal Separate Storm Sewer System (MS4) permit that was issued to the City of Harrisonburg to help control impacts caused by stormwater runoff from urban areas (VPDES # VAR040075). 33 of the 38 point sources potentially discharge bacteria to streams in the Smith Creek watershed, as detailed in Section 3. The MS4 permit load was calculated based on the load contributed by urban (built-up) lands in the watershed and the percentage of urban land within the Harrisonburg city limits. The bacteria load contributed by all other VPDES facilities was calculated based on the permitted flow (1,000 gallons/day for general permits) and the applicable *E. coli* limit (126 cfu/100ml, geometric mean concentration).

Table 8.1 VPDES point sources and existing loads

VPDES Permit No.	Facility	Flow (MGD)	Permit Limit (E. coli cfu/100ml)	Existing Annual Load (E. coli cfu/yr)
VA0027626	Valley View Mobile Home Court	0.0200	126	3.48E+10
VA0054453	New Market Poultry Products	0.3000	126	5.22E+11
VA0071846	Endless Caverns Inc	0.0046	126	8.01E+09
VA0080535	Two Hills Inc STP	0.0054	126	9.40E+09
VA0077399	Lacey Spring Elementary School STP	0.0075	126	1.31E+10
VA0090794	Holtzman Express-Mauzy	0.0060	126	1.04E+10
VA0088994	Harrisonburg-New Market KOA	0.0100	126	1.74E+10
VA0083305	Camp Overlook	0.0300	126	5.22E+10
VAG408049	Private Residence	0.0010	126	1.74E+09
VAG401001	Private Residence	0.0010	126	1.74E+09
VAG401128	Private Residence	0.0010	126	1.74E+09
VAG401201	Private Residence	0.0010	126	1.74E+09
VAG401179	Private Residence	0.0010	126	1.74E+09
VAG401363	Private Residence	0.0010	126	1.74E+09
VAG401492	Private Residence	0.0010	126	1.74E+09
VAG401537	Private Residence	0.0010	126	1.74E+09
VAG401551	Private Residence	0.0010	126	1.74E+09
VAG401405	Private Residence	0.0010	126	1.74E+09
VAG401890	Private Residence	0.0010	126	1.74E+09
VAG401956	Private Residence	0.0010	126	1.74E+09
VAG401966	Private Residence	0.0010	126	1.74E+09
VAG401961	Private Residence	0.0010	126	1.74E+09
VAG401805	Private Residence	0.0010	126	1.74E+09
VAG401920	Private Residence	0.0010	126	1.74E+09
VAG401432	Private Residence	0.0010	126	1.74E+09
VAG401988	Private Residence	0.0010	126	1.74E+09
VAG401998	Private Residence	0.0010	126	1.74E+09
VAG408026	Private Residence	0.0010	126	1.74E+09
VAG408028	Private Residence	0.0010	126	1.74E+09
VAG408029	Private Residence	0.0010	126	1.74E+09
VAG408030	Private Residence	0.0010	126	1.74E+09
VAG408035	Private Residence	0.0010	126	1.74E+09
VA0091235	Shenandoah Fisheries, Ltd	N/A	N/A	0
VAG110131	Superior Concrete Central Plant	N/A	N/A	0
VAR100591	Rockingham Redi-Mix Inc	N/A	N/A	0
VAR102386	Holtzman Express-Mauzy	N/A	N/A	0
VAR051331	Harper's Lawn Ornaments	N/A	N/A	0
VAR040075	City of Harrisonburg - MS4 Permit	N/A	126	2.88E+12
Total	All Permits	0.4075		3.59E+12

* MGD = million gallons per day

8.3 Load Allocations

Load allocations to nonpoint sources are divided into land-based loads from land uses in the watershed and direct discharges from straight pipes, cattle, and wildlife. Failing septic discharges were included in the built up (urban land) load. Also, the built up load expressed in the following tables represents the bacteria load contributed by urban lands outside the Harrisonburg city limits - MS4 permitted area.

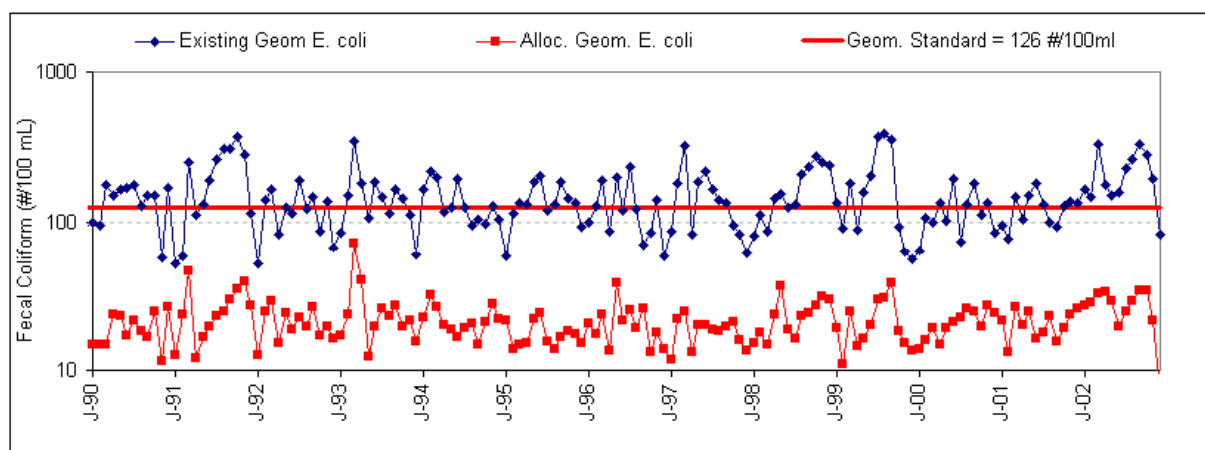
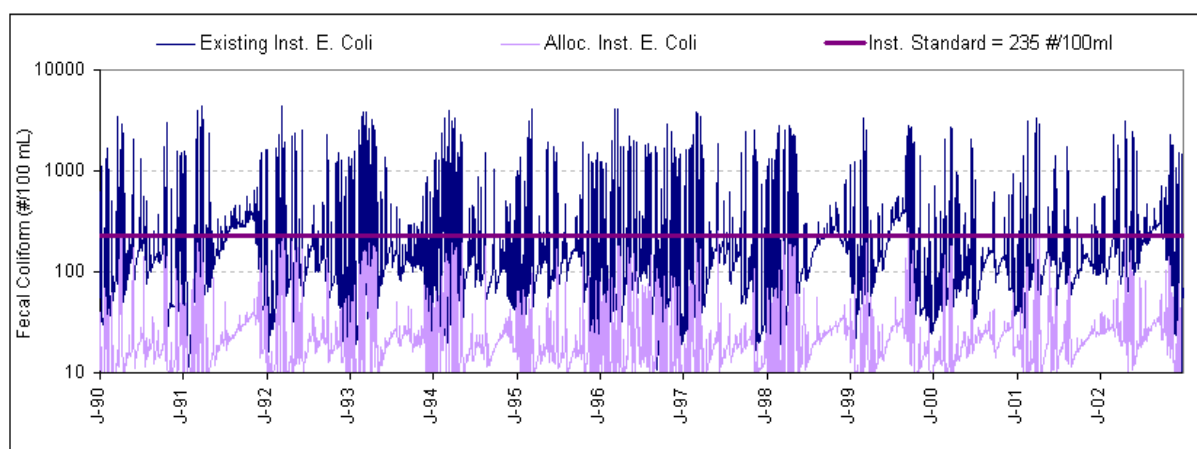
Using the model developed to represent existing conditions, various allocation scenarios were examined for reducing *E. coli* loads to levels that would result in the attainment of water quality standards. This examination focused on understanding the water quality response and sensitivity of Smith Creek to variations in source loading characteristics.

Allocation scenarios are presented with percent violations between 1/1/1990 and 12/31/2002 in Table 8.2. Scenario 6 presents the source reductions required to achieve the *E. Coli* instantaneous and calendar month geometric mean criteria. Scenario 3 presents the reductions required to meet the Stage 1 implementation goal of <10% violation of the instantaneous criteria. The calendar month geometric mean concentration for existing and the final allocation scenario are shown in Figure 8.1. The instantaneous concentration for existing and the final allocation scenario are shown in Figure 8.2. Reductions in load contributions from in-stream sources had the greatest impact on *E. coli* concentrations. Significant reductions from land-based loadings were also required to meet water quality standards. Direct deposition during low flow conditions and loads transported by runoff during high flow conditions are controlled in these allocation scenarios.

To account for possible future growth in the *E. coli* load contributed by non-stormwater point source facilities in the watershed, the model was run with the load contributed by each bacteria point source multiplied by a factor of 5. The Harrisonburg MS4 permit load was not increased in this scenario (existing load assigned). This change resulted in an increase in the instantaneous criteria (235 cfu/100ml) percent violation rate from 0% to 0.2%. The calendar month geometric mean (126 cfu/100ml) violation rate remained at 0%. See Appendix A for figures showing the instantaneous and geometric mean allocation concentrations for Smith Creek including this point source future growth scenario. The existing load contributed by each facility is reported in the following tables.

Table 8.2 TMDL allocation scenarios and percent violations

Scenario Number	Direct (Instream) Sources			Indirect (NPS) Sources				Percent Violations	
	Straight Pipes	Livestock	Wildlife	Cropland	Pasture	Built up	Forest	Inst. Exceeds 235 cfu/100ml	Geom. Exceeds 126 cfu/100ml
1	0	0	0	0	0	0	0	20%	42%
2	50	50	0	50	50	50	0	11%	6%
3	100	60	0	50	50	60	0	10%	4%
4	75	75	0	75	75	75	0	5%	1%
5	80	80	0	85	85	85	0	2%	0%
6	100	95	0	92	92	95	0	0%	0%

**Figure 8.1 Calendar month geometric mean concentrations for existing and final allocation scenario****Figure 8.2 Instantaneous concentrations for existing and final allocation scenario**

The Load Allocations (LAs) and Waste Load Allocations (WLAs) under Scenario 6 are presented in Table 8.3 and Table 8.4, respectively. The load allocation in this scenario includes a 92% reduction in cropland and pasture land-based sources in the watershed, and a 95% reduction in built up (urban) land-based sources in the watershed. No reductions are required in forest land-based sources in the watershed. In addition, this load allocation scenario includes a 100% reduction in direct deposition of *E. coli* bacteria from straight pipes, and a 95% reduction in direct deposition of *E. coli* from livestock. No reduction in direct deposition of *E. coli* from wildlife is required. The TMDL is presented in Table 8.5.

Table 8.3 Existing and allocation loads for LAs under allocation scenario 6

Sources		Total Annual Loading for Existing Conditions (cfu/yr)	Total Annual Loading for Allocation Conditions (cfu/yr)	Percent Reduction
Direct	Straight Pipes	<1.00E+4	<1.00E+4	100%
	Livestock	1.68E+13	8.38E+11	95%
	Wildlife	2.64E+12	2.64E+12	0%
Indirect	Cropland*	3.45E+13	2.76E+12	92%
	Pasture**	5.93E+13	4.74E+12	92%
	Built up***	1.15E+13	5.77E+11	95%
	Forest****	8.65E+11	8.65E+11	0%
Total		1.26E+14	1.24E+13	90%

* Includes Barren

** Includes Hayland

*** Non MS4 Urban Pervious and Urban Impervious

**** Includes Wetland

Table 8.4 Existing and allocation loads for WLAs under allocation scenario 6

Sources	Total Annual Loading for Existing Conditions (E. coli cfu/yr)	Total Annual Loading for Allocation Conditions (E. coli cfu/yr)	Percent Reduction
Permits*	7.09E+11	7.09E+11	0%
MS4 - VAR040075	2.88E+12	1.44E+11	95%
Total	3.59E+12	8.53E+11	76%

* Total for all permits, excluding the Harrisonburg MS4 permit.

Table 8.5 *E. coli* TMDL for Smith Creek

WLA	LA	MOS	TMDL
8.53E+11	1.24E+13	Implicit	1.33E+13

8.4 Consideration of Critical Conditions

The LSPC model is a continuous-simulation model; therefore, all flow conditions are taken into account for loading calculations. The modeling period represents typical high and low flow periods in the watershed; therefore, loads contributed through direct deposition (e.g., cattle in streams) and through runoff under critical conditions were accounted for in the model.

8.5 Consideration of Seasonal Variations

Seasonal variation was explicitly included in the modeling approach for this TMDL. Bacteria accumulation rates for each land use were determined on a monthly basis. The monthly accumulation rates accounted for the temporal variation in activities within the watershed, including seasonal application of agricultural waste, grazing schedules of livestock, and seasonal variation in number of cows in the stream. Also, the use of continuous simulation modeling resulted in consideration of the seasonal aspects of rainfall patterns. In addition, seasonal variation was accounted for in the allocation scenario.

SECTION 9

TMDL METHODOLOGY - SEDIMENT

9.1 TMDL Calculation

Impaired and reference watershed models were calibrated for hydrology using different modeling periods and weather input files. To establish baseline (reference watershed) loadings for sediment, the GWLF model results for the Hays Creek watershed (reference) were used. For TMDL calculation, both the calibrated impaired and reference watersheds were run for a 12-year period from 4/1/1990 to 3/31/2002. The Smith Creek model weather file was used to run the reference model also. This was done to standardize the modeling period and weather data. Based on the availability of weather and flow data, it is assumed that this period sufficiently captures hydrologic and weather conditions. In addition, the total area for the reference watershed was reduced to be equal to the target watershed, as discussed in Section 5.3. This was necessary because watershed size influences sediment delivery to the stream and other model variables.

The 11-year means for pollutants of concern were determined for each land use/source category in the impaired and the reference watersheds. The first year of the model run was excluded from the pollutant load summaries because the GWLF model takes a few months in the first year to stabilize. Model output for Smith Creek is only presented for the years following the initialization year, although the model was run for a 12-year time period (4/1990 - 3/2002). The existing average annual sediment loads for the Smith Creek watershed are presented in Table 9.1.

Table 9.1 Existing sediment loading in the Smith Creek watershed

Source Category	Sediment Load (pounds per year)	Sediment % of Total
Forest	299,718	1.0%
Water	0	0.0%
Pasture/Hay	24,410,967	78.6%
Cropland	5,411,881	17.4%
Transitional	465,460	1.5%
Urban (pervious & impervious)	99,517	0.3%
Groundwater	0	0.0%
Point Sources	334,069	1.1%
MS4 Permit	25,381.5	0.1%
Total Existing Load	31,046,995	100.0%

The TMDLs established for Smith Creek consist of a point source wasteload allocation (WLA), a nonpoint source load allocation (LA), and a margin of safety (MOS). The sediment TMDL for the Smith Creek watershed was based on the total load calculated for the Hays Creek reference

watershed (area adjusted to the impaired watershed size). Loads for urban areas have been lumped together (pervious and impervious). The sediment loadings from the impervious urban areas were estimated by multiplying literature values of the unit area loading rates (840 kg/ha/yr) times the impervious urban area in the watershed.

Note that the MS4 permit load was calculated based on the load contributed by urban (built-up) lands in the watershed and the percentage of urban land located within the Harrisonburg city limits. The urban load expressed in these tables represents the sediment load contributed by urban lands outside the Harrisonburg city limits - MS4 permitted area.

The TMDL equation is as follows:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

The WLA portion of this equation is the total loading assigned to point sources. The LA portion represents the loading assigned to nonpoint sources. The MOS is the portion of loading reserved to account for any uncertainty in the data and the computational methodology used for the analysis. An explicit MOS of 10% was used in TMDL calculations to provide an additional level of protection for designated uses.

The TMDL for Smith Creek (entire watershed) was calculated by adding reference watershed loads for sediment together with point source loads to give the TMDL value (Table 9.2).

Table 9.2 Sediment TMDL for the Smith Creek watershed

TMDL (lbs/yr)	WLA (lbs/yr) (including MS4)	LA (lbs/yr)	MOS (lbs/yr)	Overall % Reduction
27,062,901	353,867	24,002,222	2,706,812	21.6%

9.2 Wasteload Allocation

A wasteload allocation was assigned to the point source facilities in the watershed. As discussed in Section 6, the sediment load contributed by each facility was calculated based on the type of VPDES permit (individual, general, stormwater, MS4) and the current permit conditions. The sediment load contributed by individual and general permits was calculated based on the permitted flow (1000 gallons/day for general permits) and the applicable TSS limit (typically 30 mg/L for general permits). Stormwater permit loads were calculated using a threshold TSS value of 100 mg/l and the estimated average annual runoff for the permitted area (based on modeling results). The sediment load contributed by the MS4 permit during runoff events was calculated based on the modeling results for urban lands located within the City of Harrisonburg and the Smith Creek watershed.

Although reductions were made to the MS4 permitted load from the City of Harrisonburg, all other

current permit requirements are expected to result in attainment of WLAs as required by the TMDL without any reductions. Note that the WLA value presented in the previous table represents the sum of all point source WLAs in the watershed, including the MS4 permit load. The sediment load allocated to each permitted facility in the watershed is presented in Table 9.3. The Shenandoah Fisheries (VPDES VA0091235) sediment WLA was based on the organic solids TMDL that was recently developed for Lacey Spring Branch (VADEQ 2002). The current permit for this facility was issued on 5/16/03 and expires on 2/9/07. The permit includes interim and final limits for total suspended solids (TSS - sediment). Interim TSS limits (10 mg/l daily average, 15 mg/l daily maximum), were incorporated to allow the facility time to make the improvements necessary to comply with the stated final TSS limits (0.46 kg/day average, 0.92 kg/day maximum). No further reductions from this facility are required above those required in the Lacey Spring Branch TMDL.

Table 9.3 Wasteload allocation (WLA) for the Smith Creek watershed

VPDES Permit No.	Facility Name	Discharge Type	Design Flow (MGD)	Permitted Concentration (mg/L) or Load (kg/day)	TSS load (lbs/yr)
VA0027626	Valley View Mobile Home Court	General	0.02	45	2,735.9
VA0054453	New Market Poultry Products	General	0.3	147	134,382.8
VA0071846	Endless Caverns Inc	General	0.0046	117	1,641.6
VA0080535	Two Hills Inc STP	General	0.0054	45	740.3
VA0077399	Lacey Spring Elementary School STP	General	0.0075	45	1,030.0
VA0090794	Holtzman Express-Mauzy	General	0.006	45	820.8
VA0091235	Shenandoah Fisheries, Ltd	General	N/A	0.46 kg/day average (final permit limit)	370.2
VA0088994	Harrisonburg-New Market KOA	General	0.01	45	1,368.0
VA0083305	Camp Overlook	General	0.03	45	4,112.0
VAG408049	Private Residence	Stormwater	N/A	30	91.4
VAG401001	Private Residence	Stormwater	N/A	30	91.4
VAG401128	Private Residence	Stormwater	N/A	30	91.4
VAG401201	Private Residence	Stormwater	N/A	30	91.4
VAG401179	Private Residence	Stormwater	N/A	30	91.4
VAG401363	Private Residence	Stormwater	N/A	30	91.4
VAG401492	Private Residence	Stormwater	N/A	30	91.4
VAG401537	Private Residence	Stormwater	N/A	30	91.4
VAG401551	Private Residence	Stormwater	N/A	30	91.4
VAG401405	Private Residence	Stormwater	N/A	30	91.4
VAG401890	Private Residence	Stormwater	N/A	30	91.4
VAG401956	Private Residence	Stormwater	N/A	30	91.4
VAG401966	Private Residence	Stormwater	N/A	30	91.4
VAG401961	Private Residence	Stormwater	N/A	30	91.4
VAG401805	Private Residence	Stormwater	N/A	30	91.4
VAG401920	Private Residence	Stormwater	N/A	30	91.4
VAG401432	Private Residence	Stormwater	N/A	30	91.4
VAG401988	Private Residence	Stormwater	N/A	30	91.4
VAG401998	Private Residence	Stormwater	N/A	30	91.4
VAG408026	Private Residence	Stormwater	N/A	30	91.4
VAG408028	Private Residence	Stormwater	N/A	30	91.4
VAG408029	Private Residence	Stormwater	N/A	30	91.4
VAG408030	Private Residence	Stormwater	N/A	30	91.4
VAG408035	Private Residence	Stormwater	N/A	30	91.4
VAG110131	Superior Concrete Central Plant	Stormwater	N/A	30	91.4
VAR100591	Rockingham Redi-Mix Inc	Stormwater	N/A	100	98,000.1
VAR102386	Holtzman Express-Mauzy	Stormwater	N/A	100	69,253.4
VAR051331	Harper's Lawn Ornaments	Stormwater	N/A	100	17,329.7
VAR040075	City of Harrisonburg MS4	Stormwater	N/A	N/A	19,797.6
Total Load					353,867.0

9.3 Load Allocation

Load or wasteload allocations were assigned to each source category in the watershed. Several allocation scenarios were developed for the Smith Creek watershed to examine the outcome of various load reduction combinations. The recommended scenario for Smith Creek (Table 9.4) is based on maintaining the existing percent load contribution from each source category. Two additional scenarios are presented for comparison purposes (Table 9.5). Load reductions from agricultural sources are minimized in the first alternative and reductions from urban lands are minimized in the second alternative. The recommended scenario balances the reductions from agricultural and urban sources by maintaining existing watershed loading characteristics. In each scenario, loadings from certain source categories were allocated according to their existing loads. For instance, sediment loads from forest lands represent the natural condition that would be expected to exist; therefore, the loading from forest lands was not reduced. Also, sediment loads were reduced for the MS4 permit, but no reductions were made to other point sources because these facilities are currently meeting their pollutant discharge limits and other permit requirements. Current permit requirements are expected to result in attainment of the WLAs as required by the TMDL. Note that the sediment WLA values presented in the following tables represent the sum of all point source WLAs.

Table 9.4 Recommended sediment allocations for the Smith Creek watershed

Source Category	Sediment Load Allocation (lbs/yr)	Sediment % Reduction
Forest	299,718	0.0%
Water	0	0.0%
Pasture/Hay	19,040,555	22.0%
Cropland	4,221,267	22.0%
Transitional	363,059	22.0%
Urban (pervious & impervious)	77,623	22.0%
Groundwater	0	0.0%
Point Sources	334,069	0.0%
MS4	19,798	22.0%
TMDL Load (minus MOS)	24,356,089	21.6%

Table 9.5 Alternative sediment allocations for the Smith Creek watershed

Source Category	Minimize Agricultural Reductions	Minimize Urban Reductions
Forest	0.0%	0.0%
Water	0.0%	0.0%
Pasture/Hay	20.5%	22.5%
Cropland	20.5%	22.0%
Transitional	97.0%	0.0%
Urban (pervious & impervious)	97.0%	0.0%
Groundwater	0.0%	0.0%
Point Sources	0.0%	0.0%
MS4 Permit	97.0%	0.0%

9.4 Consideration of Critical Conditions

The GWLF model is a continuous-simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values. Therefore, all flow conditions are taken into account for loading calculations. Because there is usually a significant lag time between the introduction of sediment to a waterbody and the resulting impact on beneficial uses, establishing this TMDL using average annual conditions is protective of the waterbody.

9.5 Consideration of Seasonal Variations

The continuous-simulation model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model requires specification of the growing season and hours of daylight for each month. The combination of these model features accounts for seasonal variability.

SECTION 10

REASONABLE ASSURANCE AND IMPLEMENTATION

10.1 TMDL Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the benthic impairments on Smith Creek, Mountain Run, and Fridley Run, and the bacteria impairments on Smith Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at <http://www.deq.state.va.us/tmdl/implans/ipguide.pdf>. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

10.2 Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plans. While specific goals for BMP implementation will be established as part of the implementation plan development, for the bacteria TMDL the following stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

10.3 Stage 1 Scenario

The goal of the stage 1 scenario is to reduce the bacteria loadings from controllable sources, such that violations of the single sample maximum criterion (235 cfu/100mL) are less than 10 percent. The stage 1 scenario was generated with the same model setup as was used for the TMDL allocation scenarios. This scenario is presented with the other allocation scenarios in Section 8.

10.4 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the 2001 Interim Nutrient Cap

Strategy for the Shenandoah/Potomac basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (2001 Draft Interim Nutrient Cap Strategy for the Shenandoah/Potomac River Basins). The BMPs required for the implementation of the sediment allocations in the watersheds contribute directly to the sediment reduction goals set as part of the Chesapeake Bay restoration effort. A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. The draft tributary strategy for the Shenandoah-Potomac River Basin will be made available in April 2004. Up-to-date information on tributary strategy development can be found at <http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm>.

10.5 Reasonable Assurance for Implementation

10.5.1 Follow-Up Monitoring

VADEQ will continue monitoring 1BSMT004.60 and 1BSMT023.18 in accordance with its ambient monitoring program to evaluate reductions in bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards. VADEQ will also continue monitoring 1BSMT006.62 in accordance with its biomonitoring program. VADEQ will continue to use data from these monitoring stations and related ambient monitoring stations to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

10.5.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plans, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plans into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

10.5.3 Stormwater Permits

It is the intention of the Commonwealth that the TMDLs will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for storm water discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:...(2) Numeric effluent limitations are infeasible,...".

Part of the Smith Creek watershed is covered by Phase II VPDES permit VAR040075 for the small municipal separate storm sewer systems (MS-4) owned by the City of Harrisonburg. This permit was issued on 5/16/2003. The effective date of coverage is 12/9/2007. The permit states, under Part II.A., that the "permittee must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law."

The permit also contains a TMDL clause that states: "If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of storm water discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Storm Water Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL."

For MS4/VPDES general permits, DEQ expects revisions to the permittee's Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern. DEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions.

However, only failing to implement the required BMPs would be considered a violation of the permit. DEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 10.5.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change on Smith Creek would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia's Storm Water Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at <http://www.deq.state.va.us/water/bmps.html>.

10.5.4 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

10.5.5 Proposed Water Quality Standards Revisions

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria will become effective pending EPA approval and can be found at <http://www.deq.state.va.us/wqs/rule.html>.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be

able to provide comment during this process. Additional information can be obtained at <http://www.deq.state.va.us/wqs/WQS03AUG.pdf>.

Based on the above, EPA and Virginia have developed the following TMDL implementation process. First in this process is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 10.1 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources.

SECTION 11

PUBLIC PARTICIPATION

A stakeholder and TMDL study kickoff meeting was held on April 25, 2003 at the Arthur L. Hildreth, Jr. Municipal Building (New Market Town Hall) in New Market, Virginia. A site visit to the Smith Creek watershed was also conducted on this date. Important information regarding likely stressors and sources was discussed with state environmental personnel and local stakeholders.

The first public meeting on the development of TMDLs for the Smith Creek watershed was held on August 27, 2003 from 7-10 p.m. at the Arthur L. Hildreth, Jr. Municipal Building (New Market Town Hall) in New Market, Virginia. Approximately 20 people attended the meeting. Copies of the presentation materials were made available for public distribution at the meeting. No written comments were received.

The second and final public meeting on the TMDLs development for the Smith Creek watershed will be held on March 15, 2004 from 7-10 p.m. at the Tenth Legion Ruritan Hall in Tenth Legion, Virginia. Approximately 33 people attended the meeting. Copies of the Draft TMDL report and presentation materials were made available for public distribution at the meeting. Written comments were received and VADEQ responded to each commentor and addressed all comments. Appropriate revisions were made to this document in response.

REFERENCES

- ASAE Standards, 45th Edition. 1998. *Manure production and characteristics*. St. Joseph, MI
- Bicknell, B.R., J.C. Imhoff, J.L. Kittle, A.S. Donigian, and R.C. Johanson. 1996. *Hydrological Simulation Program - Fortran User's Manual for Release 11*. U.S. Environmental Protection Agency. Athens, GA.
- Census. 2000. *Virginia geographic comparisons*. U.S. Census Bureau. Washington, D.C.
- Cormier, S., G. Suter, and S. B. Norton. 2000. *Stressor identification: Technical guidance document*. EPA-822-B-00-025. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development. Washington, D.C.
- Dai, T., R.L. Wetzel, T. R. Christensen, and E.A. Lewis. 2000. *BasinSim1.0: A windows-based watershed modeling package*. Virginia Institute of Marine Science. College of William and Mary. Gloucester Point, VA.
- Dunn, T. and L.B. Leopold. 1978. *Water in Environmental Planning*. W. H. Freeman Press. San Francisco, CA.
- Haith, D.A., and L.L. Shoemaker. 1987. *Generalized watershed loading functions for stream flow nutrients*. Water Resources Bulletin 23(3):471-478.
- Haith, D.A., R. Mandel, and R.S. Wu. 1992. *GWLF: Generalized Watershed Loading Functions User's Manual, Version 2.0*. Department of Agriculture and Biological Engineering, Cornell University, Ithaca, NY.
- Hamon, R.W. 1961. *Estimating Potential Evapotranspiration*. Proceedings of the American Society of Civil Engineers, Journal of the Hydraulic Division. Vol. 87, No. HY3, p 107-120.
- Hayward, R.S., and F.J. Margraf. 1987. *Eutrophication effects on prey size and food available to yellow perch in Lake Erie*. Transactions of the American Fisheries Society 116(2):210-223.
- Leach, J.H., M.G. Johnson, J.R.M. Kelso, J. Hartmann, W. Numann, and B. Entz. 1977. *Response of percid fishes and their habitats to eutrophication*. Journal of the Fisheries Research Board of Canada 34:1964-1971.
- Mara, D.D. and J.I. Oragui. 1981. *Occurrence of Rhodococcus coprophilus and associated antinomycetes in feces, sewage, and freshwater*. Appl. Environ. Microbiol. 42:1037-1042.

- Metcalf and Eddy, Inc. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse*. 3rd edition. McGraw-Hill. New York, NY.
- NAS/NAE. 1972. *Water Quality Criteria 1972: Summary of Some Effects of pH on Freshwater Fish and Other Aquatic Organisms*. Environmental Studies Board, National Academy of Sciences/National Academy of Engineering. Washington, D.C.
- NRCS. 1994. *State Soil Geographic (STATSGO) Data Base*. U.S. Department of Agriculture, Natural Resources Conservation Service. Fort Worth, TX.
- Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish*. U.S. Environmental Protection Agency, Office of Water Regulations and Standards. Washington, D.C. EPA 440-4-89-001.
- SERCC. 2003. *Historical climate summaries for Virginia*. Southeast Regional Climate Center. South Carolina Department of Natural Resources, Water Resources Division. Columbia, SC.
- USEPA. 1991. *Guidance for Water Quality-Based Decisions: The TMDL Process*. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 440/4-91-001.
- USEPA. 1992. *Multi-Resolution Land Cover (MRLC) Data for Virginia, a Component of the National Land Cover Dataset (NLCD)*. U.S. Environmental Protection Agency and the U.S. Geological Survey. Reston, VA.
- USEPA. 2003. *A Stream Condition Index for Virginia Non-Coastal Streams*. U.S. Environmental Protection Agency, Office of Science and Technology, Office of Water, and USEPA Region III (Wheeling, WV), Washington, D.C., Prepared by Tetra Tech, Inc., Owings Mills, MD.
- USGS. 2002. *Fecal coliform bacteria TMDL for Blacks Run, Rockingham County, Virginia*. U.S. Geological Survey, Richmond, VA.
- VADCR. 2002. *Modeling Cattle Stream Access*. Virginia Department of Conservation and Recreation. Richmond, VA.
- VADEQ. 1998. *Virginia's 1998 Total Maximum Daily Load Priority List and Report*. Virginia Department of Environmental Quality, Richmond, VA.
- VADEQ. 2000. *Fecal coliform TMDL (Total Maximum Daily Load) development for South Fork of the Blackwater River, Virginia*. Virginia Department of Environmental Quality. Richmond, VA.

- VADEQ. 2001. *Fecal coliform TMDL, Mountain Run Watershed, Culpeper County, Virginia*. Virginia Department of Environmental Quality. Richmond, VA.
- VADEQ. 2002a. *Virginia's 2002 Total Maximum Daily Load Priority List and Report*. Virginia Department of Environmental Quality. Richmond, VA.
- VADEQ. 2002b. *Benthic TMDL Reports for Six Impaired Stream Segments in the Potomac-Shenandoah and James River Basins*. Virginia Department of Environmental Quality. Richmond, VA.
- VADEQ. 2002c. *Water Quality Assessment Guidance Manual for Y2002 350(b) Water Quality Report and 303(d) Impaired Waters List*. Virginia Department of Environmental Quality. Richmond, VA.
- VADEQ. 2003. *Guidance Memo No. 03-2012: HSPF Model Calibration and Verification for Bacteria TMDLs*. Virginia Department of Environmental Quality. Richmond, VA.
- VASS. 1997. *Virginia Agricultural Statistics*. U.S. Department of Agriculture, Virginia Agricultural Statistics Service. Washington, D.C.
- Woods, A.J., J.M. Omernik, and D.D. Brown. 1999. *Level III and IV Ecoregions of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia*. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory. Corvallis, OR.

Glossary

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.

Aquatic ecosystem. Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.

Background levels. Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.

Bacteria. Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.

Bacterial decomposition. Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Basin. A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.

BasinSim 1.0. GWLF based modeling interface developed by Dai et al. 2000.

Benthic. Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.

Benthic organisms. Organisms living in, or on, bottom substrates in aquatic ecosystems.

Best management practices (BMPs). Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Calibration. The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Clean Water Act (CWA). The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.

Concentration. Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).

Confluence. The point at which a river and its tributary flow together.

Contamination. The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.

Conventional pollutants. As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.

Cost-share program. A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).

Critical condition. The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the

pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.

Decay. The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.

Decomposition. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also Respiration.

Designated uses. Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.

Discharge. Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.

Discharge Monitoring Report (DMR). Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.

Discharge permit (see VPDES). A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System (NPDES), under provisions of the Federal Clean Water Act.

Diurnal. Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours.

Domestic wastewater. Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.

Dynamic model. A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.

Ecosystem. An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.

Effluent. Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.

Empirical model. Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.

Endpoint. An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).

E. coli. *Escherichia coli* is a bacterium that is commonly found in the digestive tract of warm blooded animals. Various strains can cause gastrointestinal illness and other infections.

Enterococci. A subgroup of fecal streptococci bacteria that can cause gastroenteritis.

Failing Septic System. Typically an older or improperly maintained septic systems that discharges waste to the soil surface where it is available for washoff into surface waters.

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth.

Ground water. The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.

GWLF. Generalized Watershed Loading Functions. Empirical watershed loading model developed by Cornell University (Haith and Shoemaker 1987; Haith et al. 1992)

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrologic cycle. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.

Hydrology. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Indicator organism. An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.

KLSCP. A composite factor used to measure soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P).

Loading, Load, Loading rate. The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.

Load allocation (LA). The portion of a receiving water's loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).

Loading capacity. The greatest amount of loading a water can receive without violating water quality standards.

LSPC. Loading Simulation Program C++

Margin of safety (MOS). A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a $TMDL = LC = WLA + LA + MOS$).

Metrics. Measurements of the benthic community which are used to assess biological condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.

Monitoring. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

MRLC. Multi Resolution Land Characteristics. Land use coverage developed by USEPA and USGS.

MS4. Multiple Separate Storm Sewer System

MUID. Soil map unit in the STATSGO database developed by NRCS. A map unit is composed of several soil series that have similar properties.

Narrative criteria. Nonquantitative guidelines that describe the desired water quality goals.

National Pollutant Discharge Elimination System (NPDES). The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.

Natural waters. Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.

NCDC. National Climatic Data Center

NHD. National Hydrography Dataset (developed by USGS)

Nonpoint source. Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

NRCS. Natural Resource Conservation Service.

Numeric targets. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.

Organic matter. The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.

Permit. An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

Phased Implementation. Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.

Point source. Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollutant. Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).

Pollution. Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and

radiological integrity of water.

Public comment period. The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).

Rapid Bioassessment Protocol (RBP). Various methods that are used to assess the biological condition of waterbodies.

Receiving waters. Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.

Reference watershed. A non-impaired watershed with similar characteristics that is used to define the baseline, reference, or natural condition.

Residence time. Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.

Restoration. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.

Riparian areas. Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.

Riparian zone. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.

Runoff. That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Sewer. A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.

Simulation. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Slope. The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

STATSGO. State Soil Geographic database developed by NRCS

Straight Pipe. Illicit and untreated discharge of waste typically from a private home.

Stream restoration. Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.

Stressor Identification. Refers to the identification of stressors causing biological impairment in aquatic ecosystems. Methodology was developed by USEPA and Tetra Tech, Inc.

Surface water. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

Taxa. A taxonomic group of any rank, including all the subordinate groups. Any group of organisms, populations, or taxa considered to be sufficiently distinct from other such groups to be treated as a separate unit.

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Topography. The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.

Total Maximum Daily Load (TMDL). The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Tributary. A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

Total Suspended Solids (TSS). A measure of the amount of suspended material in the water column.

USEPA. United States Environmental Protection Agency

USGS. United States Geological Survey

USLE. Universal Soil Loss Equation. Equations used to calculate soil loss/erosion.

Validation. Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

Virginia Stream Condition Index (VaSCI). Bioassessment index that provides a detailed assessment of the benthic macroinvertebrate community in Virginia's wadeable, non-coastal streams. Developed by USEPA, VADEQ, and Tetra Tech, Inc (2003).

VDH. Virginia Department of Health.

VDGIF. Virginia Department of Game and Inland Fisheries.

Virginia Pollutant Discharge Elimination System (VPDES). The Virginia state program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.

Wasteload allocation (WLA). The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Wastewater. Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.

Wastewater treatment. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.

Water quality. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.

Water quality criteria. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water quality standard. Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

Watershed. A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

WQIA. Water Quality Improvement Act.

APPENDIX A

Point Source - Future Growth Scenario

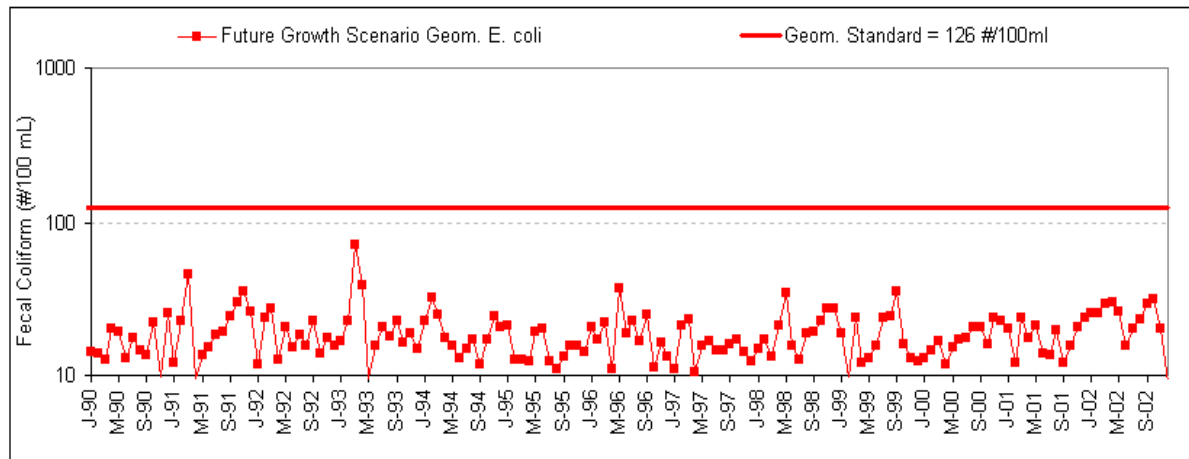


Figure A.1 Calendar month geometric mean concentrations for final allocation scenario, including point source future growth

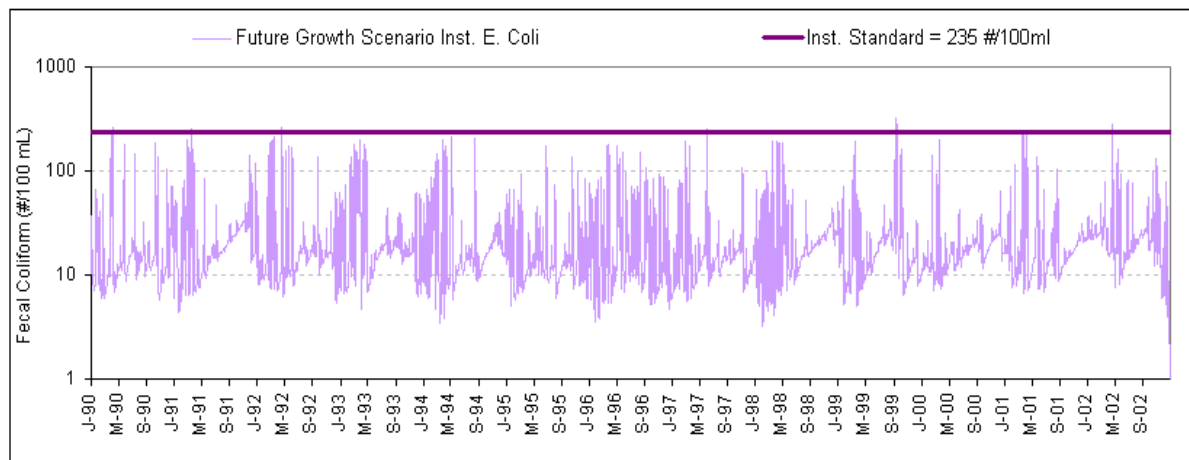


Figure A.2 Instantaneous concentrations for final allocation scenario, including point source future growth